Dairy Production Medicine

Edited by Carlos A. Risco and Pedro Melendez

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This book is dedicated to my family Omi, Carlos, Cristina, and Jacqueline, for their support and encouragement to practice my profession with unwavering dedication at the expense of shared time together.

Carlos A. Risco

I would like to dedicate this book to my wife Maria Ester, my children Diego, Ignacio, and Elisa, my father, and brother Oscar, and specially my mother Eliana, who recently passed away, for their unconditional support, and understanding of my devotion to this wonderful profession.

Pedro Melendez Retamal

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Preface

Dairy farming is an important component of agriculture worldwide because of the value of milk to human nutrition. However, the production of milk at the farm level is under constant economical, societal, and environmental challenges which places constraints for dairy farmers to meet the demands of an increasing world population for a wholesome and economical supply of milk. Consequently, dairy farmers must continuously modify and adapt management of their milk production system to meet these challenges by relying on specialists to provide them with management guidelines.

Dairy production medicine integrates specialties of veterinary medicine and animal science into a dairy production system designed to produce milk in a profitable manner. The approach to the design, implementation, and management of this system is multidisciplinary and includes clinical medicine, economics, epidemiology, food safety, genetics, human resource management, nutrition, preventive medicine, and reproduction. These specialties must work in concert to harmonize management of the individual dairy farm in order to obtain a profit without neglecting animal welfare and food safety.

Our premise for this book is the recognition that a book that integrates the above-mentioned specialties within the context of production medicine is lacking for dairy cattle. This book covers production medicine in relation to the production cycle of the dairy cow and replacement heifer. Within this context, components of the production cycle include the nonlactating, post partum, and breeding periods. For each component, appropriate management for a successful outcome is addressed.

During the last 30 years, the role of veterinarians working with dairy cattle has changed from an emphasis on clinical medicine to consulting, evaluation of herd performance, and employee training. Therefore, our goal for this book is to provide students, veterinarians, and dairy specialists with a reference for dairy production medicine that can be used to provide dairy herd management services. In doing so, we recognize that a dairy herd is composed of individual animals that must be housed in a comfortable environment, fed to meet their nutrient requirements according to their stage of production, and provided with prompt treatment of disease. If at the individual animal level these requirements are met, the overall animal well-being of the herd improves commensurate with societal expectations for the care of food-producing animals.

Because of the breadth of expertise that is required to write a book on dairy cattle production medicine, we solicited the contribution of talented individuals. We are grateful to them and acknowledge their valuable contribution.

Carlos A. Risco
Gainesville, Florida
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Acknowledgments

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Carlos A. Risco

I would like to acknowledge my colleagues and friends in academia for their wise assistance, and to my students for the satisfaction they have given me. Finally, I want to express my sincere gratitude to my past and current clients who have trusted in my knowledge, attitude, and professionalism.

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1

Management Considerations from Parturition to the End of the Voluntary Waiting Period to Optimize Health and Reproductive Performance

Carlos A. Risco

Abstract

From an animal health and well-being and performance perspective, the postpartum period is composed of an early window where health greatly impacts production and reproductive efficiency. Thus, appropriate management during this period is critical to ensure a normal state of cow health at the herd level to optimize production and reproductive performance. This chapter discusses management considerations from parturition to the end of the voluntary waiting period to optimize health and reproductive performance.

Introduction

Reproductive efficiency is vital for the economic viability of a dairy farm because it increases the likelihood of cows remaining in the herd, increases the number of cows that spend their productive life in profitable milk production, increases the number of calves born per year, and reduces involuntary culling (de Vries, 2006). However, reproductive efficiency has decreased in lactating dairy cows worldwide as evidenced by a reduction in conception rates (Macmillan et al., 1996; Royal et al., 2000; Lucy, 2001; de Vries, 2006). Although causes for this decline are multifactorial, attenuation of estrus expression in high-producing cows (Wiltbank et al., 2006), embryonic mortality (Santos et al., 2001), energy metabolism during early postpartum, and its interactions with immune function play a major role (Hammon et al., 2006). Further, the trend for larger herds coupled with labor shortage has resulted in new challenges in compliance with health and reproductive programs. Thus, opportunities abound for veterinarians to work with dairy producers to implement a sound reproductive management program to mitigate the effect of these factors on reproductive efficiency.

Pregnancy rate (PR) determines the calving to conception interval (CCI) at the end of the voluntary waiting period (VWP). As PR increases, the CCI is reduced, thereby increasing the amount of milk produced per day of herd lifetime and reducing the number of cows culled for reproductive failure, which collectively increases herd income (Risco et al., 1998; de Vries, 2006). Thus, it is clear that the challenge for both producers and veterinarians is to employ a reproductive program that attains and maintains a herd PR commensurate with a profitable production of milk.

Typically, reproductive programs for dairy herds are established with the goal of increasing PR (no. of pregnant animals divided by no. of cows eligible to become pregnant in a 21-day interval) at the end of the VWP by employing estrous synchronization protocols to increase insemination rates. However, it is critical to convey to producers that events that occur during parturition have a profound effect on fertility at the end of the VWP by predisposing cows to calving-related disorders that affect uterine health and resumption of ovarian cyclicity. That is, cows that do not "transition" well from parturition to lactation have a lower risk of becoming pregnant from the application of these synchronization protocols at the

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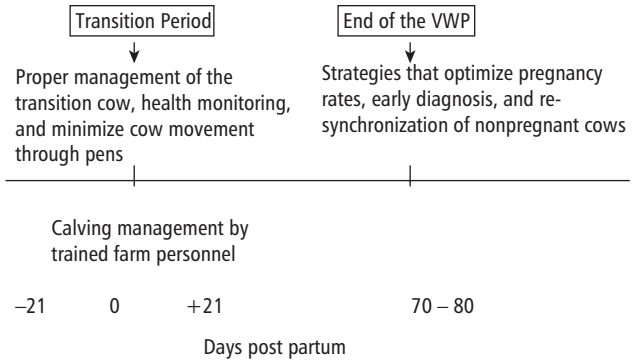

Figure 1.1. Management considerations from calving to the end of the voluntary waiting period (VWP) to optimize health and fertility.

end of the VWP. Therefore, reproductive management of dairy cows must integrate management strategies that optimize cow health from the time prior to parturition until the end of the VWP, as shown in Figure 1.1.

Management of the Transition Period

The majority of diseases that affect cow health occur during the transition period (3 weeks before and after parturition) are a consequence of parturition and initiation of lactation. These diseases include dystocia, hypocalcemia, ketosis, retained fetal membranes (RFMs), uterine infections, displaced abomasum, and mastitis. Alone or together, these diseases have been shown to affect postpartum health by lowering subsequent milk production and reproductive performance (Gröhn et al., 1990)

As discussed in Chapter 2, the challenge in transition cow nutrition is to implement feeding strategies before calving to optimize immune function at calving by allowing peripartal cows to recover quickly from hypocalcemia and negative energy balance. In many dairy herds, attention to transition cow management occurs after health problems have occurred. Therefore, periodic evaluation of the management given to both pre- and postpartum cows is recommended to control the prevalence of calving-related disorders. The following checklist provides a guide to determine whether management of transition cows is appropriate.

- Is the ration balanced for energy, fiber content (including effective fiber), protein, minerals, and vitamins?
- What is the dietary cationic/anionic proportion of the ration, including the potassium percentage of the roughage source?
- Is there enough feed bunk space for prepartum cows (at least 0.60 m per cow)?
- Is there adequate shade for heat stress abatement (4.65 m^2 per cow)?
- Are employees trained and supervised for proper calving assistance and treatment of postpartum diseases?
- Are urine pHs evaluated to ascertain compliance of appropriate anionic diet feeding?
- Are pre- and postpartum energy status evaluated in selected groups to determine prevalence of subclinical ketosis?
- Are body condition scores evaluated?

Calving Management

Dairy farm employees play a major role in carrying out reproductive and health programs. They do more than just inseminate and milk cows. A case in point is health monitoring to diagnose and treat diseases. In reality, to the dairy practitioner they are "health technicians," similar to those employed by companion animal veterinarians. Consequently, training programs that define the role of the employee, the "how to," and the "why" should be an integral component of dairy cattle production medicine.

On many dairy farms, there are inadequately trained employees who perform obstetrical procedures that result in calving trauma. *Who* treats, *what* training have they received, and *when* and *how* they treat calving-related problems are important questions that veterinarians should ask herd managers. Therefore, veterinarians should work closely with producers to design a herd health protocol that emphasizes first-aid calving assistance to discourage employees from using improper techniques for delivering calves (Chapter 3).

Moving Fresh Cows Through Pens Before and After Calving

Cow behavior and social factors can be primary risks for the development of ketosis, fatty liver, and displaced abomasum. Where poorly formulated rations and inaccurate delivery systems are considered primary risk factors for these conditions, poorly staged pen moves and overstocking are major risk factors (Nordlund et al., 2008). The mechanism appears to be a disruption of dry matter intake for vulnerable cows, leading to ketosis followed by the cascade of diseases related to ketosis.

To simplify labor, dairy farms commonly use a grouping system of cows for specialized management, which includes

- Far-off dry cows: from –60 to –21 days from calving
- Close-up dry cows: from –20 to –3 days from calving
- Maternity pen
- Fresh pen: 3–14 days after calving
- Sick pen: variable days after calving
- Various lactation and pregnant groups

In the aforementioned scenario, cows are often moved multiple times during the transition period, a time when cows are most vulnerable to develop subclinical ketosis. In general, cows resident in a pen tend to maintain their rank compared with new arrivals (Schein & Fohrman, 1955). With each movement to a new pen or group, a cow experiences stress and must establish her rank within the social order of the pen; feed intake is reduced. Early lactation cows are more affected by regrouping than mid-lactation cows, and cows that are losing weight lose social rank within a group, while those gaining weight gain dominance. These observations suggest that too many cow movements early postpartum impacts fresh cow health, as the early postpartum period is a period of significant weight loss.

Due to the daily cow entry or regrouping that occurs in the hospital pen, Cook and Nordlund (2004) have described this event as a state of constant "social turmoil" as each new cow attempts to establish her rank within the social order of the pen. In essence, this regrouping or mixing of cows decreases feed intake as well as the number of aggressive interactions in which the new cow is involved (von Keyserlingk et al., 2008). In other words, the newly moved cow is more timid and stays away from the feed bunk. We need to ask ourselves the effect of regrouping on a sick cow which is already off feed and immune compromised. Therefore, producers under the guidance of their veterinarians must use good judgment when deciding which cow to treat and if the treatment requires milk discard and thus cow movement to the hospital pen. A case in point are cows with uterine infections such as metritis that require antibiotic treatment. With the commercial availability of antibiotics labeled for treatment of metritis, where milk discard is not required, cows with metritis can be treated with these antibiotics and remain in the milk herd avoiding the negative effect of regrouping.

Postpartum Health Monitoring

A major goal for transition cow management is to maintain a dairy cow healthy during early postpartum (first 3 weeks after calving). In doing so, we must recognize that the earlier a sick animal is found and treated, the quicker her chances for returning to a normal state of health.

Postpartum health monitoring programs have become popular on dairy farms. Monitoring postpartum health involves the examination of all cows during early postpartum (first 12 days) by trained farm personnel. Parameters that can be used to evaluate health status of cows include rectal temperature, attitude, milk production, uterine discharge, and urine ketones. Veterinarians have an opportunity to expand their services to dairy producers by implementing training programs for farm employees to "look" for sick cows using time-effective techniques to identify animals in the early stages of disease and to allow for effective treatment (Chapter 4).

Strategies to Maximize PR at the End of the VWP

The VWP is the time during early lactation that producers choose not to breed cows despite their being in estrus. In a survey conducted in dairy herds participating in a progeny test program, the VWP range varied from 30 to 90 days postpartum with a mean of 56 ± 0.6 days (DeJarnette et al., 2007). In that survey, reasons for selectively altering the VWP were postpartum health issues, parity, milk production, and season.

During the VWP cows are in a negative energy balance, are anovular, and have some degree of uterine infection, which is detrimental to fertility. Recovery from these conditions can be viewed as a physiological requirement for an optimal time to pregnancy at the end of the VWP. In the author's opinion, extending the VWP to 75 days postpartum is a sufficient time to allow cows to recover from these conditions and experience multiple estrous cycles prior to first insemination.

On many dairy farms, failure to detect cows in estrus results in a calving to first insemination interval to extend well beyond the established VWP. The application of ovulation synchronization protocols that allow for fixed time insemination with acceptable PRs has been shown to dramatically lower the interval from calving to first insemination. The economic value of the use of these ovulation synchronization protocols, such as Ovsynch, depends on the estrus detection rate of the herd. In those herds with high estrus detection rate, the value of Ovsynch is lower. This concept was illustrated in a study that reported the value of a pregnancy based on insemination at detected estrus or Ovsynch in two herds (Tenhagen et al., 2004). One-half of each herd was inseminated at detected estrus, the other half was inseminated with OvSynch. In one herd with poor estrus detection, the cost of a pregnancy was reduced significantly with the use of OvSynch compared with insemination at detected estrus. In the second herd, which had higher estrus detection rates, the cost of a pregnancy was slightly more for OvSynch, despite improved reproductive performance. The greatest costs attributed to lower PRs from insemination at detected estrus were higher culling rates and excessive days nonpregnant.

Potential net returns per cow were modeled by comparing the use of Ovsynch in winter and summer compared with insemination at detected estrus (Risco et al.,

1998). The greatest impact on net returns was obtained when Ovsynch was used during summer compared with winter. This finding was attributed to lower estrus detection rates observed during the summer months. Results from these studies indicate that the use of an ovulation synchronization protocol such as OvSynch is an economical alternative in reproductive management of dairy herds with poor estrus detection.

Early Diagnosis of Nonpregnant Cows

The value of early pregnancy diagnostics is finding a nonpregnant cow earlier followed by a successful rebreeding to reduce days not pregnant. Palpation per rectum is effective after days 33–35 and ultrasonography by day 28. Pregnancy-specific protein B (PSPB) is present in cells of the developing trophoblast as early as day 21 of pregnancy in cows (Humblot et al., 1988). Detection of this protein in blood is a good indicator of pregnancy as early as 30 days of gestation. Because of its long half-life, it remains in circulation for several months after parturition. Therefore, in cows diagnosed pregnant that lose their pregnancy, residual PSPB can cause a false positive result. Currently, blood samples for cows that are greater than 90 days postpartum and 30 days postbreeding are shipped to the laboratory for analysis (BioPRYN®; Ag Health, Sunnyside, WA, http://www.aghealth.com). A study that compared pregnancy diagnosis in dairy cattle by the use of a commercial (BioPRYN) PSPB enzyme-linked immunosorbent assay (ELISA) and palpation per rectum showed good agreement between the two tests (Breed et al., 2009). Discrepant results were attributable to a nonviable fetus, embryonic loss, or fetal loss. The authors concluded that the pregnancy diagnostic error and the delayed return of results for the PSPB ELISA results, compared with the diagnostic accuracy and immediacy of obtaining results for palpation per rectum, are drawbacks for the PSPB ELISA.

None of these pregnancy tests is faultless, and unacceptable test sensitivity and specificity can occur. The decision as to which "test" to use for early diagnosis of nonpregnant cows should be based on practicality, cost, and practitioner comfort level. Regardless of which test is used, it is critical that veterinarians engaged in reproductive management institute a program that allows for the identification of bred cows that are not pregnant early followed by rebreeding. Further, due to embryonic mortality, cows diagnosed as pregnant should be reconfirmed at a later date to identify those cows that have aborted and are nonpregnant so that they can be rebred in a timely manner.

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Introduction

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Typically, reproductive programs for dairy herds are established with the goal of increasing PR (no. of pregnant animals divided by no. of cows eligible to become pregnant in a 21-day interval) at the end of the VWP by employing estrous synchronization protocols to increase insemination rates. However, it is critical to convey to producers that events that occur during parturition have a profound effect on fertility at the end of the VWP by predisposing cows to calving-related disorders that affect uterine health and resumption of ovarian cyclicity. That is, cows that do not "transition" well from parturition to lactation have a lower risk of becoming pregnant from the application of these synchronization protocols at the

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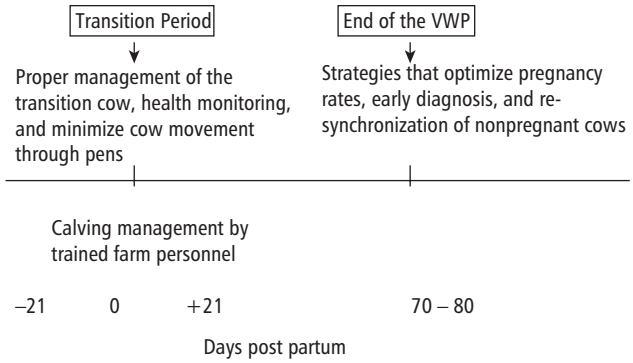

Figure 1.1. Management considerations from calving to the end of the voluntary waiting period (VWP) to optimize health and fertility.

end of the VWP. Therefore, reproductive management of dairy cows must integrate management strategies that optimize cow health from the time prior to parturition until the end of the VWP, as shown in Figure 1.1.

Management of the Transition Period

The majority of diseases that affect cow health occur during the transition period (3 weeks before and after parturition) are a consequence of parturition and initiation of lactation. These diseases include dystocia, hypocalcemia, ketosis, retained fetal membranes (RFMs), uterine infections, displaced abomasum, and mastitis. Alone or together, these diseases have been shown to affect postpartum health by lowering subsequent milk production and reproductive performance (Gröhn et al., 1990)

As discussed in Chapter 2, the challenge in transition cow nutrition is to implement feeding strategies before calving to optimize immune function at calving by allowing peripartal cows to recover quickly from hypocalcemia and negative energy balance. In many dairy herds, attention to transition cow management occurs after health problems have occurred. Therefore, periodic evaluation of the management given to both pre- and postpartum cows is recommended to control the prevalence of calving-related disorders. The following checklist provides a guide to determine whether management of transition cows is appropriate.

- Is the ration balanced for energy, fiber content (including effective fiber), protein, minerals, and vitamins?
- What is the dietary cationic/anionic proportion of the ration, including the potassium percentage of the roughage source?
- Is there enough feed bunk space for prepartum cows (at least 0.60 m per cow)?
- Is there adequate shade for heat stress abatement (4.65 m^2 per cow)?
- Are employees trained and supervised for proper calving assistance and treatment of postpartum diseases?
- Are urine pHs evaluated to ascertain compliance of appropriate anionic diet feeding?
- Are pre- and postpartum energy status evaluated in selected groups to determine prevalence of subclinical ketosis?
- Are body condition scores evaluated?

Calving Management

Dairy farm employees play a major role in carrying out reproductive and health programs. They do more than just inseminate and milk cows. A case in point is health monitoring to diagnose and treat diseases. In reality, to the dairy practitioner they are "health technicians," similar to those employed by companion animal veterinarians. Consequently, training programs that define the role of the employee, the "how to," and the "why" should be an integral component of dairy cattle production medicine.

On many dairy farms, there are inadequately trained employees who perform obstetrical procedures that result in calving trauma. *Who* treats, *what* training have they received, and *when* and *how* they treat calving-related problems are important questions that veterinarians should ask herd managers. Therefore, veterinarians should work closely with producers to design a herd health protocol that emphasizes first-aid calving assistance to discourage employees from using improper techniques for delivering calves (Chapter 3).

Moving Fresh Cows Through Pens Before and After Calving

Cow behavior and social factors can be primary risks for the development of ketosis, fatty liver, and displaced abomasum. Where poorly formulated rations and inaccurate delivery systems are considered primary risk factors for these conditions, poorly staged pen moves and overstocking are major risk factors (Nordlund et al., 2008). The mechanism appears to be a disruption of dry matter intake for vulnerable cows, leading to ketosis followed by the cascade of diseases related to ketosis.

To simplify labor, dairy farms commonly use a grouping system of cows for specialized management, which includes

- Far-off dry cows: from –60 to –21 days from calving
- Close-up dry cows: from –20 to –3 days from calving
- Maternity pen
- Fresh pen: 3–14 days after calving
- Sick pen: variable days after calving
- Various lactation and pregnant groups

In the aforementioned scenario, cows are often moved multiple times during the transition period, a time when cows are most vulnerable to develop subclinical ketosis. In general, cows resident in a pen tend to maintain their rank compared with new arrivals (Schein & Fohrman, 1955). With each movement to a new pen or group, a cow experiences stress and must establish her rank within the social order of the pen; feed intake is reduced. Early lactation cows are more affected by regrouping than mid-lactation cows, and cows that are losing weight lose social rank within a group, while those gaining weight gain dominance. These observations suggest that too many cow movements early postpartum impacts fresh cow health, as the early postpartum period is a period of significant weight loss.

Due to the daily cow entry or regrouping that occurs in the hospital pen, Cook and Nordlund (2004) have described this event as a state of constant "social turmoil" as each new cow attempts to establish her rank within the social order of the pen. In essence, this regrouping or mixing of cows decreases feed intake as well as the number of aggressive interactions in which the new cow is involved (von Keyserlingk et al., 2008). In other words, the newly moved cow is more timid and stays away from the feed bunk. We need to ask ourselves the effect of regrouping on a sick cow which is already off feed and immune compromised. Therefore, producers under the guidance of their veterinarians must use good judgment when deciding which cow to treat and if the treatment requires milk discard and thus cow movement to the hospital pen. A case in point are cows with uterine infections such as metritis that require antibiotic treatment. With the commercial availability of antibiotics labeled for treatment of metritis, where milk discard is not required, cows with metritis can be treated with these antibiotics and remain in the milk herd avoiding the negative effect of regrouping.

Postpartum Health Monitoring

A major goal for transition cow management is to maintain a dairy cow healthy during early postpartum (first 3 weeks after calving). In doing so, we must recognize that the earlier a sick animal is found and treated, the quicker her chances for returning to a normal state of health.

Postpartum health monitoring programs have become popular on dairy farms. Monitoring postpartum health involves the examination of all cows during early postpartum (first 12 days) by trained farm personnel. Parameters that can be used to evaluate health status of cows include rectal temperature, attitude, milk production, uterine discharge, and urine ketones. Veterinarians have an opportunity to expand their services to dairy producers by implementing training programs for farm employees to "look" for sick cows using time-effective techniques to identify animals in the early stages of disease and to allow for effective treatment (Chapter 4).

Strategies to Maximize PR at the End of the VWP

The VWP is the time during early lactation that producers choose not to breed cows despite their being in estrus. In a survey conducted in dairy herds participating in a progeny test program, the VWP range varied from 30 to 90 days postpartum with a mean of 56 ± 0.6 days (DeJarnette et al., 2007). In that survey, reasons for selectively altering the VWP were postpartum health issues, parity, milk production, and season.

During the VWP cows are in a negative energy balance, are anovular, and have some degree of uterine infection, which is detrimental to fertility. Recovery from these conditions can be viewed as a physiological requirement for an optimal time to pregnancy at the end of the VWP. In the author's opinion, extending the VWP to 75 days postpartum is a sufficient time to allow cows to recover from these conditions and experience multiple estrous cycles prior to first insemination.

On many dairy farms, failure to detect cows in estrus results in a calving to first insemination interval to extend well beyond the established VWP. The application of ovulation synchronization protocols that allow for fixed time insemination with acceptable PRs has been shown to dramatically lower the interval from calving to first insemination. The economic value of the use of these ovulation synchronization protocols, such as Ovsynch, depends on the estrus detection rate of the herd. In those herds with high estrus detection rate, the value of Ovsynch is lower. This concept was illustrated in a study that reported the value of a pregnancy based on insemination at detected estrus or Ovsynch in two herds (Tenhagen et al., 2004). One-half of each herd was inseminated at detected estrus, the other half was inseminated with OvSynch. In one herd with poor estrus detection, the cost of a pregnancy was reduced significantly with the use of OvSynch compared with insemination at detected estrus. In the second herd, which had higher estrus detection rates, the cost of a pregnancy was slightly more for OvSynch, despite improved reproductive performance. The greatest costs attributed to lower PRs from insemination at detected estrus were higher culling rates and excessive days nonpregnant.

Potential net returns per cow were modeled by comparing the use of Ovsynch in winter and summer compared with insemination at detected estrus (Risco et al.,

1998). The greatest impact on net returns was obtained when Ovsynch was used during summer compared with winter. This finding was attributed to lower estrus detection rates observed during the summer months. Results from these studies indicate that the use of an ovulation synchronization protocol such as OvSynch is an economical alternative in reproductive management of dairy herds with poor estrus detection.

Early Diagnosis of Nonpregnant Cows

The value of early pregnancy diagnostics is finding a nonpregnant cow earlier followed by a successful rebreeding to reduce days not pregnant. Palpation per rectum is effective after days 33–35 and ultrasonography by day 28. Pregnancy-specific protein B (PSPB) is present in cells of the developing trophoblast as early as day 21 of pregnancy in cows (Humblot et al., 1988). Detection of this protein in blood is a good indicator of pregnancy as early as 30 days of gestation. Because of its long half-life, it remains in circulation for several months after parturition. Therefore, in cows diagnosed pregnant that lose their pregnancy, residual PSPB can cause a false positive result. Currently, blood samples for cows that are greater than 90 days postpartum and 30 days postbreeding are shipped to the laboratory for analysis (BioPRYN®; Ag Health, Sunnyside, WA, http://www.aghealth.com). A study that compared pregnancy diagnosis in dairy cattle by the use of a commercial (BioPRYN) PSPB enzyme-linked immunosorbent assay (ELISA) and palpation per rectum showed good agreement between the two tests (Breed et al., 2009). Discrepant results were attributable to a nonviable fetus, embryonic loss, or fetal loss. The authors concluded that the pregnancy diagnostic error and the delayed return of results for the PSPB ELISA results, compared with the diagnostic accuracy and immediacy of obtaining results for palpation per rectum, are drawbacks for the PSPB ELISA.

None of these pregnancy tests is faultless, and unacceptable test sensitivity and specificity can occur. The decision as to which "test" to use for early diagnosis of nonpregnant cows should be based on practicality, cost, and practitioner comfort level. Regardless of which test is used, it is critical that veterinarians engaged in reproductive management institute a program that allows for the identification of bred cows that are not pregnant early followed by rebreeding. Further, due to embryonic mortality, cows diagnosed as pregnant should be reconfirmed at a later date to identify those cows that have aborted and are nonpregnant so that they can be rebred in a timely manner.

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2

Nutritional Management of the Prepartum Dairy Cow

Pedro Melendez Retamal

Abstract

During the postpartum period, dairy cows are at a high risk to develop metabolic diseases that impair milk production and subsequent reproductive performance. Many of these diseases are the result of improper nutritional management during the dry period. Because dry cows do not contribute to the milk check, many producers ignore these animals, and their nutritional needs are compromised. Veterinarians must convince dairy producers that the dry period is a preparatory phase for the next lactation and that dry cows must be considered an investment for the next lactation. Evaluation of the prepartum cow program should be an important component of any dairy herd health program. Prepartum transition dairy cows should be managed and fed so that at parturition and initiation of lactation, the cow is physiologically prepared to make the necessary adjustments to calcium and energy demands. If a dairy farm experiences an unacceptable level of parturient paresis, retained fetal membranes (RFMs), ketosis, or digestive disorders, changes in prepartum transition nutrition program and management would be prudent.

Introduction

When a dairy cow is dried off at around 7 months of gestation, her lactational nutritional needs decrease. After that, and while the fetus continues to grow and dry matter intake (DMI) starts to decrease, energy balance declines during the last 30 days of gestation. Therefore, dry cows should be separated, managed, and fed as two different groups. The first group of dry cows would include cows from the day they are dried off, and the second group would include those that are around 21 days before expected parturition. The first group is the so-called far-off or early dry cows. Approaching 30 days before expected parturition, the requirements of the dry cow start to increase to a level in which nutrient density should be intermediate compared with the far-off dry cow and milking-cow diets. This cow is the so-called close-up or prepartum transition dairy cow. A series of recent studies have been conducted to investigate if the length of the dry period could be shortened to handle only one group of dry cows, to obtain extra milk and to achieve more profit for the producer. Until now, results have been scarce and inconsistent. As a result and until more data are available, a range of 50–70 days for a dry period is still recommended, and two groups of dry cows (far-off and close-up) are proposed.

The Transition Period

The transition period is defined as the time from the last 3 weeks of gestation until 3 weeks postparturition. During this period, the cow experiences remarkable metabolic and endocrine changes to which she needs to properly adjust in order to have a successful lactation period. During the last weeks of gestation, DMI begins

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to decrease dramatically, with the lowest level occurring at calving. Parturition and the onset of lactation impose tremendous physiological challenges to calcium and energy balance, and immunosuppression is a common feature. This may predispose the dairy cow to disorders such as parturient paresis, dystocia, retained fetal membranes (RFMs), metritis, mastitis, and ketosis (Goff & Horst, 1997). These disorders result in significant economic losses to the dairy industry by reducing reproductive performance and milk yield. Proper nutrition and feeding management play a key role in minimizing these disorders and allow a smooth transition from late gestation to early lactation.

From a practical standpoint, four major goals must be achieved during the prepartum period to succeed during lactation: (1) adapt the rumen to a high-energy diet, (2) minimize the degree of negative energy balance, (3) minimize the degree of hypocalcemia, and (4) reduce the degree of immunosuppression around parturition. A brief review of the physiological and metabolic changes that occur around this time is presented in the following paragraphs.

Nutritional Physiology

One of the most remarkable changes during the transition period is the reduction in DMI that starts a few weeks before parturition with the lowest level occurring at calving. DMI decreases about 32% during the final 3 weeks of gestation, and 89% of that decline occurs at 5–7 days before calving (Drackley, 1999; Drackley et al., 2001). Most cows rapidly increase DMI during the first 3 weeks after parturition. As a result, DMI should be addressed strategically during the prepartum period. It has been shown that cows that have less DMI prior to calving experience more postpartum disorders (metritis, fatty liver, ketosis) than cows that eat normally(Grummer et al., 2004; Urton et al., 2005).

Fetal and placental growth occurs exponentially, with over 60% taking place during the last 2 months of gestation. Glucose and amino acids are the major fuel supply of the developing fetus in ruminants. Glucose is also needed by the mammary gland for lactose synthesis, and amino acids for milk protein synthesis. Adult dairy cattle are not entirely dependent on dietary glucose; as a result, they are in a constant stage of gluconeogenesis from propionic acid produced in rumen. Gluconeogenesis occurs in the liver, which is the key organ regulator of glucose supply to the rest of the body. Concurrently, the cow starts to mobilize fat from triglycerides (TGs) in the form of nonesterified fatty acids (NEFA); its concentration starts to increase during the last week of gestation with the maximum level reached at parturition (0.9–1.2 mEq/L), with a slow decrease after 3 days postpartum. However, when extreme rates of lipid mobilization occur, as in the case of obese animals, it may lead to increased uptake of NEFA by the liver and increased TG accumulation with consequent fatty liver development. When blood glucose concentrations are high, insulin is released, and lipogenesis predominates over lipolysis, with suppression of NEFA release from adipose tissue. When blood glucose levels are low, and NEFA levels are not extremely high, transport of NEFA into the mitochondria in liver is favored, and ketone body formation increases (Herdt, 2005).

Endocrine regulation of gluconeogenesis, ketogenesis, and lipid metabolism is a complex mechanism that involves several hormones. A summary of hormones and other metabolic mediators is shown in Table 2.1.

DMI

Adequate management of the transition dairy cow includes avoiding excessive depression of DMI during the prepartum period and stimulating DMI as soon as possible during the early postpartum period. For this purpose, cows and heifers should be housed in two dif-

Table 2.1. Effect of hormones on carbohydrate and lipid metabolites on dairy cattle

Hormone	Effect on carbohydrates	Effect on lipids
Insulin	↑ Glucose transport into cells ↓ Gluconeogenesis ↑ Glycogen synthesis ↓ Glucogenolysis ↑ Glycolisis	↓ Lipolysis ↑ Lipogenesis
Glucagon	↑ Gluconeogenesis ↑ Glycogenolysis ↑ Glucose export ↓ Glycolisis ↓ Glycogen synthesis	↑ Lipolysis ↑ Ketogenesis
Catecholamines	↑ Glycogenolysis ↑ Gluconeogenesis ↑ Glucagons secretion ↓ Insulin secretion	↑ Lipolysis
Growth hormone	↑ Blood glucose	↓ Lipogenesis ↑ NEFA mobilization
Cortisol	↑ Gluconeogenesis from proteins	↑ Lipolysis

Source: Herdt (2005).

ferent pens to avoid competition and excessive dominance. This grouping makes possible the formulation of two diets according to physiological differences between heifers and adult, mature dairy cows (National Research Council (NRC), 2001; Grummer et al., 2004).

Sufficient shade, water of good quality, feed bunk space, and comfortable housing conditions are essential. A total mixed ration (TMR) using the same ingredients to be included in the lactating diet and offered at least twice a day should be fed to both prepartum and postpartum transition cows.

Transition cows should always have fresh feed in their feed bunk, and refusals should constitute 2%–4% of diet offered. Diet ingredients such as silage with the most variable dry matter (DM) content should be evaluated periodically to make adjustments necessary to maintain the recommended DM content of the TMR.

Grouping Strategies

It is recommended to manage prepartum primiparous and multiparous cows in two separate groups. By keeping multiparous and primiparous together, they have stronger social interactions, and more competition is evident. In addition, they have different nutrient requirements and physiological divergences. As an example, primiparous cows are still growing, and multiparous cows are more likely to develop milk fever. Consequently, when primiparous cows are grouped separately from multiparous cows, they eat longer, consume more DM, rest for extended periods, and produce more milk.

Energy Status and Nutrition

Body condition score (BCS), NEFA in blood, and ketone bodies in blood, urine, or milk are useful tools to evaluate the energy status and nutrition of dairy cattle. During the transition period, feed intake is decreasing at a time when energy requirements are increasing due to growth of the conceptus. Consequently, to maintain energy balance, the energy density of the diet should be increased (NRC, 2001). By doing that, energy density will stimulate papillae growth and increase acid absorption from the rumen, adapt the microbial population to higher starch diets, increase blood insulin and decrease fatty acid mobilization from adipose tissue, and increase DMI (Grummer et al., 2004).

Because cows inevitably experience negative energy balance close to calving and after parturition, they lose BCS during the first 100 days of lactation. As a result, it is important that the cow calves in an optimum BCS to sustain milk yield without affecting potential fertility. For this reason, BCS should be handled strategically during the last third of lactation and eventually during the dry period. If many cows are overconditioned during mid-lactation, a fat cow group fed only for maintenance should be established in late lactation. Cows should never lose BCS during the dry period. If many cows are underconditioned, a thin cow group fed adequate energy to target the desired weight gain should be established. The use of monensin during the entire dry period in cows dried off with BCS 2.75 or less has been demonstrated to improve BCS at calving (3.25) compared with a control group without monensin (BCS 3.0 at calving). The group with monensin produced more milk and had fewer metabolic disorders than the control group after parturition (Melendez et al., 2007).

If cows are too fat (BCS $\geq$ 4.0) during the dry period, losses of body weight should be avoided, and prevention of fatty liver should be considered. The use of rumen-protected choline has been demonstrated to help prevent excessive fat mobilization and improve lactational performance (Zahra et al., 2006).

As was mentioned before, cows with increased levels of NEFA precalving experience more dystocia, RFMs, ketosis, DA, and mastitis compared with cows with low NEFA (Dyk et al., 1995; Melendez et al., 2009). Therefore, monitoring blood NEFA prepartum or at calving periodically (once a month) can be a useful tool to test herd health status. New evidence on dry cow nutrition suggests that overfeeding cows during the far-off period induces higher levels of serum NEFA and ketone bodies and losses of more body weight during the close-up period. Nevertheless, animals that are fed a high-energy density diet (1.70 Mcal of NE_L/kg) during the close-up period had higher plasma concentrations of glucose and insulin and lower concentrations of NEFA 7 days before expected parturition (BEP) compared with animals fed a low-energy density diet (1.58 Mcal of NE_L/kg). Nonetheless, energy density of prepartum diet has a minor influence on postpartum metabolic status of cows compared with energy density of diets fed during the first 3 weeks of lactation (Dann et al., 2006; Douglas et al., 2006).

Ketosis is a metabolic disorder characterized by high levels of ketone body production with the highest incidence between 14 and 21 days postpartum. However, ketone bodies can also be high before parturition, and sometimes it is useful to evaluate them prior to calving. The most common methodology is the use of a colorimetric test to detect the presence of acetoacetate in urine. The test is highly specific and moderately sensitive (Carrier et al., 2004). This evaluation can be done when urine samples are obtained for urine pH assessment in herds using anionic diets for hypocalcemia prevention. Result of the tests should be negative prepartum. If the result is positive, the case should be treated immediately. If prepartum ketosis is a problem, the entire nutrition program of the transition cow should be evaluated.

Gluconeogenic precursors can be used strategically during the last 21 days of gestation and 21 days postpartum to prevent ketosis. Within these precursors, propylene glycol, calcium propionate, glycerol, and ionophores are the most popular additives used in the prepartum nutrition program, as shown in Table 2.2.

Protein Nutrition

Multiparous cows should receive a diet with 12%–13% of crude protein (CP) (35% rumen undegradable protein [RUP]). However, primiparous cows should be fed diets with 14%–15% CP with a RUP of 38%–40% of the total

Table 2.2. Additives used in prepartum dairy cows

Rumen modifiers			
Additives	Mechanism of action	Dose	Recommendations
Direct-fed microbial			
Fungal cultures (*Aspergillus oryzae*, *Saccharomyces cerevisiae*)	Stimulation of growth of certain groups of ruminal bacteria. Improve DMI. Decrease lactic acid production.	1×10^9 cfu/g 10–20 g/animal/day	Feed during the entire transition period.
Lactobacillus (*Lactobacillus acidophilus*, *Bifidobacterium animalis*)	Colonization of intestinal tract. Prevention of pathogen proliferation. Improvement of digestion.	1×10^9 cfu/g 10–20 g/animal/day	Feed during the entire transition period. Recommended in calves as well.
Ionophores			
Sodium monensin Lasalocid	Decrease gram (+) bacteria. Methane, acetate, and butyrate are decreased. Propionate is increased. Glucose production may increase. Enhancement of feed efficiency. Bloat reduction. Ketosis and NEFA reduction. Rumen pH stabilization.	250–350 mg/animal/day 200–400 mg/animal/day	In prepartum and fresh cows to prevent ketosis, reduce NEFA and prevent fatty liver. Indirectly to prevent displacement of abomasum.
Buffers			
Sodium bicarbonate Magnesium oxide Calcium carbonate	Modulation of rumen pH. Increase of dry matter intake, milk yield, and milk fat yield. Magnesium oxide supplies magnesium, and calcium carbonate supplies calcium as well.	0.6%–0.8% of DMI or 130–250 g/day	During early lactation, with large amount of highly fermentable carbohydrates, when corn silage is the major forage in diet, when concentrates and forages are fed separately, when NDF, chewing activity, and milk fat are reduced. Feed buffers after calving. Before parturition may impact negatively DCAD.
Saponins			
Yucca (*Yucca schidigera*) Quillay (*Quillaja saponaria*)	They modify microflora and rumen fermentation, and exert immunostimulatory effects. Suppression of protozoa, resulting in a reduction of ammonia production and a more efficient nitrogen utilization.	6–12 g/cow/day	Recommended in prepartum dairy cow until 100 days in milk.

Table 2.2. (*Continued*)

Rumen modifiers			
Additives	Mechanism of action	Dose	Recommendations
Glucose precursors			
Calcium propionate	Source of glucose and calcium.	150 g as feeding rate 500 g as drench	Feed during the entire transition period (top dressed). As drench mixed with 10 L of water.
Propylene glycol (1,2 propanediol)	Absorbed in intestine. Converted in glucose in liver.	240–400 g/day	Feed during the entire transition period, top dressed. As drench at calving in its liquid form.
Glycerol (1,2,3 propanediol)	Converted to glucose in liver. Reduced NEFA at calving. Still under investigation.	1.5 L as a drench at calving 165 g/day as powder	Feed during the entire transition period as powder.
Vitamins			
Protected choline	Participate in synthesis of phospholipids. Improve lactation performance. Reduced risk of clinical and subclinical ketosis. Reduced fatty liver.	15 g/animal/day	Feed pre- and postpartum especially in obese cows.
Niacin	Increased milk yield by 0.5 kg/day. Antilipolytic. Reduce ketosis and fatty liver.	6–12 g/animal/day	Feed pre-and postpartum transition cows.
Biotin	Essential for keratinization. Improved hoof health. Increase milk yield in high-producing cows.	20 mg/animal/day	Must be fed continuously to observe positive effects in hoof health.
Organic minerals			
Organic selenium	With vitamin E improve immune status of transition dairy cows. Less oxidative stress. Fewer RFMs and lower somatic cell count (SCC).	Legal limit of selenium 0.3 ppm	Feed during prepartum and first 100 days in milk.
Organic zinc	Improve claw integrity and keratin synthesis. Reduce somatic cell count and increase milk yield.	40–60 ppm	Feed during prepartum and first 100 days in milk.
Chromium propionate	Improve action of insulin. Promote intracellular glucose uptake and reduce NEFA release.	500 ppb	Feed during transition period pre- and postpartum.
Miscellaneous			
Anionic salts	Mild acidification of body. Increase Ca bioavailability. Prevention of milk fever.	100–300 g/animal/day	Only adult prepartum cows until parturition.
Methionine and analogs	Methyl donor. Essential amino acid. Improve milk protein and fat. Decrease fatty liver.	10–30 g/cow/day	Feed during transition period pre- and postpartum.

CP. This higher amount of protein is due to their growing stage, mammary gland development, and lower DMI than multiparous cows. However, the end point is to formulate for metabolizable protein (MP) (1100–1300 g of MP/cow/day) and not only for CP. Protein requirements are another reason to maintain and handle two prepartum groups (heifers and cows).

Calcium Nutrition

Hypocalcemia is a common metabolic disorder affecting dairy cattle at parturition. It may be clinical (milk fever) or subclinical. Subclinical hypocalcemia (<7.5 mg/dL) affects about 50% of all adult dairy cattle coming from a prepartum diet without the use of anionic salts or 30% of cattle coming from a prepartum diet with anionic salts (Meléndez et al., 2002). Subclinical hypocalcemia may lead to decreased DMI after calving, increased risk of secondary diseases, decreased milk production, and decreased fertility.

By restricting the calcium intake below maintenance requirements, activation of the calcium mobilization system occurs prior to parturition. Vitamin D activation is enhanced, and efficiency of bone calcium resorption and gut calcium absorption are increased. Thus, at parturition, when the severe calcium demands of lactation are initiated, calcium homeorhetic mechanisms are maximized. However, restriction of calcium intake close to recommended levels during late prepartum is not always efficacious in reducing the incidence of milk fever. Only when calcium intake is maintained below 20 g/day is prevention of milk fever more favorable. It is difficult to limit calcium intake to such low levels from the available feedstuffs used in commercial herds today.

The other most important determinant of hypocalcemia is the acid–base status of the animal at the time of parturition. Diets normally fed to cattle prior to parturition induce an alkaline response. This metabolic alkalosis alters the physiologic activity to maintain normocalcemia, reducing the ability of the animal to successfully adjust to increased calcium demands (Goff, 1999). The difference in milliequivalents between cations and anions per kilogram of dry matter (dietary cation-anion difference [DCAD]) has a direct impact on blood acid–base metabolism (Block, 1994). Diets causing a mild metabolic acidosis (richer in anions compared with cations) reduce the risk of hypocalcemia. Typical diets fed to dry cows have a DCAD of about +50 to +250 mEq/kg of DM. In common feedstuffs, potassium is the most variable of the ions in the DCAD equation, and it is usually the most important determinant of DCAD (Goff, 1999). The successful supplementation of dietary anions to prevent milk fever (MF) has suggested that diets that are high in cations, especially Na and K, increase the susceptibility of cows to MF. Potassium should be <1.5% of DM. Once the cation content has been reduced as much as possible by diet selection, anions can then be added to further reduce DCAD to the desired end point (Goff, 1999). Commonly used anion sources are calcium chloride, ammonium chloride, magnesium sulfate, ammonium sulfate, and calcium sulfate. Anionic salts can be unpalatable and are always accompanied by a cation which, depending on its rate of absorption, will counteract some of the effects of the anions (Goff & Horst, 1997). Other anion sources include mineral acids such as hydrochloric acid. Commercial preparations of HCl mixed into common feed ingredients as a premix could offer a safe and palatable alternative to anionic salts (Goff & Horst, 1998). Optimal acidification generally occurs when anions are added to achieve a final DCAD between −50 and −150 mEq/kg of DM. The strong negative relationship ($r^2 = 0.95$) between urinary pH and net acid excretion by cows fed the diets containing anionic salts suggests that urinary pH measurement is a useful tool to assess the degree of metabolic acidosis that is produced by anionic salts (Vagnoni & Oetzel, 1998). An advantage of this approach is that it accounts for inaccuracies in mineral analyses and for unexpected changes in forage mineral content. Urinary pH can be evaluated by obtaining urine from a group representing about 10% of the precalving cows. Urinary pH values below 5.5 indicate overacidification, and DCAD should be increased. The optimal urinary pH should be between 6.0 and 6.5 for Holstein cows and between 5.8 and 6.2 for Jersey cows. A urinary pH greater than 7.0 is considered inadequate acidification and suggests that a lower DCAD is required. In herds experiencing MF, the urine of close-up dry cows will be very alkaline with a pH above 8.0. Most accurate results will be obtained by collecting urine samples at a standard time, preferably within a few hours after feeding (Goff, 1999). Combining anionic salts with oral calcium and energy supplementation at calving does not seem to improve lactational performance beyond a successful use of anionic salts alone (Meléndez et al., 2002).

If the herd is not able to use anionic diets, oral calcium products at parturition should be considered. A variety of oral calcium salt preparations are available for cattle. Oral calcium supplements must be readily soluble in water and administered at doses high enough to reach the minimum concentration in the intestinal lumen to allow passive transport (~6 mmol/L) (Goff, 1999). Calcium chloride and calcium propionate are the most common products used in the treatment and prevention of hypocalcemia in cattle. Oral administration of 50 g of calcium from calcium chloride as a drench in

250 mL of water raised plasma calcium concentrations to the same extent as 4 g of calcium as calcium chloride administered intravenously. Conversely, 100 g of calcium orally from calcium propionate is equivalent to between 8 and 10 g of calcium administered intravenously. Calcium propionate is effective and is less irritating to tissues than calcium chloride. It does not induce metabolic acidosis, so larger amounts of calcium can be given. Furthermore, it supplies the cow with a gluconeogenic precursor (propionate) (Goff, 1999).

Fiber, Particle Size, and Chewing Activity

Fiber is an essential nutrient for ruminants. It can be defined as crude fiber, acid detergent fiber (ADF), neutral detergent fiber (NDF), effective NDF, and forage NDF; however, these are chemical characterizations of fiber and do not describe any particular feature related to the particle size of fiber. Methods of screening fiber particle size have been recommended. A system of particle size evaluation consisting of a top sieve with orifices of 19 mm in diameter, a second sieve with orifices of 8 mm in diameter, a third sieve with orifices of 1.18 mm in diameter, and a bottom pan without orifices to receive the finest particles has been recently developed and updated from an original system of two sieves and a bottom pan (Kononoff et al., 2003). This system is known as the Penn State Particle Separator (PSPS). At least 6%–8% of particles of a TMR should be >19 mm. This will stimulate a normal rumination process of at least 8–10 h/day. Considering the importance of this methodology, the particle size of prepartum cow's diets should be evaluated on a weekly basis.

The accuracy of chewing time prediction increases when the proportion of particles includes both coarse (>19 mm) and medium size (8–19 mm). Physically effective NDF should therefore be defined as the proportion of total diet NDF corresponding to the addition of coarse and medium fractions of the particle size separator. For example, if the total NDF of a diet is 32% and the sum of coarse and medium size particles is 40%, then peNDF will be 12.8% (32% × 0.40). Based on this definition, a value of physically effective NDF between 10% and 20% is normal and should minimally alter rumen pH and stimulate a normal chewing activity of 8 h/day (Kononoff & Heinrichs, 2003; Yang & Beauchemin, 2006).

Feed Bunk Management and Cow Behavior

The importance of feed bunk management is based on the negative effects that restricted feed intake may have in productivity and health of dairy cows. In addition, cow behavior related to feeding patterns is critical to establish consistent feeding management. However, there is a large variability between cows compared with within-cow variability regarding feeding behavior. Furthermore, feeding behavior is highly dependent on the stage of lactation (days in milk) (DeVries et al., 2003).

Feed bunk attendance is consistently higher during the day and early evening compared with the late night and early morning hours. The greatest percentage of cows attending the feed bunk area occurs after the delivery of fresh feed. In addition, a feed push-up between feedings is sufficient for greatest feeding activity. Extra feed push-up did not increase feeding activity significantly (DeVries et al., 2003; DeVries & von Keyserlingk, 2005).

Total daily feeding time increases when feed bunk space increases from 0.64 to 0.92 m/cow. The time spent standing in the feeding area while not feeding and the frequency of aggressive interactions at the feed bunk decrease when more bunk space is provided. Further, when the cows are provided with additional feeding space, particularly when combined with headlocks, cows with lower social status at the feed bunk are less likely to be displaced by other cows from the bunk. The results of this study indicate that providing 0.9 m/cow of feed bunk space would be better than the 0.5 m/cow that has been recommended traditionally (DeVries & von Keyserlingk, 2006).

Frequency of feeding is also important to consider. Feed delivery had no effect on the daily lying time of the cows or the daily incidence of aggressive interactions at the feed bunk. However, subordinate cows were not displaced as frequently when feed was offered more often. In addition, the amount of sorting of the feed was reduced by increasing the frequency of feed delivery from 1× to 2×. These results indicate that frequent delivery of feed improves access to feed for all cows, particularly during peak feeding periods when fresh feed is provided, and reduces the amount of feed sorting (DeVries et al., 2005). As a rule of thumb, the frequency of feeding should be the same as the frequency of milking in the herd, in both pre- and postpartum dairy cows. In this sense, prepartum cows will be adapted to the same routine they will experience postpartum.

Vitamin and Mineral Nutrition

Vitamins and minerals should be fed to dry cows according to the NRC recommendations. However, it should be kept in mind that the NRC requirements for dairy cows are not well defined. A summary of the nutrient requirements for a prepartum heifer and cow according to the *Nutrient Requirements of Dairy Cattle* (NRC, 2001) is shown in Table 2.3.

Table 2.3. Nutrient requirements for a prepartum heifer[1] and cow[2] according to the NRC's (2001) *Nutrient Requirements of Dairy Cattle*, 7th edition

Nutrient	Heifer standard close-up diet	Cow standard close-up diet	Cow anionic close-up diet
Energy NE_L (Mcal/kg)	1.54–1.62	1.54–1.62	1.54–1.62
Crude protein % (RDP + RUP)[3]	13.5–15.0	12.0–13.0[5]	12.0–13.0
Minimum acid detergent fiber %	21	21	21
Minimum neutral detergent fiber %	33	33	33
Maximum nonfiber carbohydrates %	43	43	43
Calcium %	0.44	0.45	0.6–1.5[6]
Phosphorus %	0.3–0.4	0.3–0.4	0.3–0.4
Magnesium %	0.35–0.4	0.35–0.4	0.35–0.4
Chloride %	0.44	0.4	0.8–1.2
Potassium %	0.55[4]	1.35	<1.3
Sodium %	0.12	0.15	0.15
Sulfur %	0.2	0.2	0.3–0.4
Cobalt mg/kg	0.11	0.11	0.11
Copper mg/kg	16	13	13
Iodine mg/kg	0.4	0.4	0.4
Iron mg/kg	26	13	13
Manganese mg/kg	22	18	18
Selenium mg/kg	0.3	0.3	0.3
Zinc mg/kg	30	22	22
Vitamin A (IU/day)	75,000	100,000	100,000
Vitamin D (IU/day)	20,000	25,000	25,000
Vitamin E (IU/day)	1200	1200	1200
Dietary cation-anion difference (DCAD) (Na + K) – (Cl + S), mEq/kg	20–200	10	–75 to 0

[1] 270 days pregnant, weighing 625 kg with conceptus, mature body weight of 680 kg, consuming 10.6 kg dry matter/day, gaining 300 g body weight plus 660 g conceptus weight each day, and a current body condition score of 3.3 and nutrient densities of an example ration that follows the recommendation guidelines.
[2] 270 days pregnant, weighing 751 kg with conceptus, mature body weight of 680 kg, consuming 13.7 kg dry matter/day, and a current body condition score of 3.3 with the nutrients supplied by the example rations that follow the recommendation guidelines.
[3] % Rumen undegradable protein (RUP) + % rumen degradable protein (RDP) = crude protein required only if ration is perfectly balanced for RDP and RUP.
[4] Goal should be to limit potassium to the requirement of the heifer to reduce udder edema. Very difficult to achieve.
[5] Cow requires 910 g/day of metabolizable protein.
[6] Utilizing the DCAD concept to prevent milk fever, diet calcium does not have to be limited.

Because of its role in prevention of RFMs, vitamin E has received much attention in recent years. Many of the studies with vitamin E have focused on its role in conjunction with selenium in prevention of RFMs. In most of these studies, reduction in the incidence of RFMs was seen after injection of 680 IU of vitamin E and 50 mg of selenium 3 weeks prepartum. In contrast, if the selenium content of the dry cow ration is >0.1–0.2 ppm, no benefits from vitamin E and selenium injection are seen. The reduction in RFMs after vitamin E and selenium supplementation has been attributed to an improved immune and antioxidant status of the cow at parturition. A description of action and levels of incorporation of minerals and vitamins are summarized in Tables 2.4 and 2.5.

Additives

Additives are defined as inert compounds or alive microorganisms added to the diet to modify rumen fermentation patterns and metabolism, to improve digestion, to

Table 2.4. Fat-soluble vitamins in dairy cattle

Vitamin	Functions	Deficiency symptoms	Common feed sources
A	Essential for normal vision; cellular function; and maintenance of epitheliums (respiratory, reproductive, and digestive tracts).	Night blindness; skin problems; blind, dead, or weak calves; reproductive failure.	Carotene sources: green forages; hays; haylages; corn silage; vitamin premix.
D	Normal bone growth and development; absorption of calcium and phosphorus; mobilization of calcium and phosphorus.	Rickets, osteomalacia.	Sun-cured forages; synthetic premixes.
E	Antioxidant; associated with selenium.	White muscle disease; cardiac muscle abnormalities; immunosuppression.	Alfalfa; germ of cereals; wheat germ oil; cereal grains; synthetic premixes.
K	Required for blood clotting.	Hemorrhaging; moldy sweet clover disease.	Green forages; normally is synthesized in the digestive tract.

Source: University of Minnesota. www.extension.umn.edu/distribution/livestocksystems/components/DI0469t02-05.html#t04.

Table 2.5. Minerals in dairy cattle

Mineral	Functions	Deficiency symptoms	Common feed sources
Calcium (Ca)	Bone formation; blood clotting; muscle contraction; 0.12% in milk.	Milk fever in adult cows; rickets in young animals; slow growth and bone development; reduced milk yield.	Alfalfa and other legumes; limestone (calcium carbonate); dicalcium phosphate.
Phosphorus (P)	Bone formation; involved in energy metabolism; part of DNA and RNA; 0.09% in milk.	Fragile bones; poor growth; depraved appetite (pica); poor reproductive performance.	Monosodium, monoammonium and dicalcium phosphates; cereal grains; grain by-products; oil seed meals.
Sodium (Na)	Acid–base balance; muscle contraction; nerve transmission.	Craving for salt; reduced appetite; if very severe: incoordination, weakness, shivering, and death.	Common salt and buffer products (sodium bicarbonate).
Chlorine (Cl)	Acid–base balance; production of hydrochloric acid in abomasum.	Craving for salt; reduced appetite.	Common salt and commercial supplements.
Magnesium (Mg)	Enzyme activator; found in skeletal tissue and bone.	Irritability; tetany; increased excitability.	Magnesium oxide; forages, and mineral supplements.
Sulfur (S)	Rumen microbial protein synthesis; found in cartilage, tendons, and amino acids.	Slow growth; reduced milk production; reduced feed efficiency.	Elemental sulfur; sodium and potassium sulfates; protein supplements; legume forages.
Potassium (K)	Maintenance of electrolyte balance; enzyme activator; muscle and nerve function.	Decreased feed intake; loss of hair glossiness; lower blood and milk potassium.	Legume forages; oat hay; potassium chloride; potassium sulfate.
Iodine (I)	Synthesis of thyroid hormones.	Goiters in calves; goitrogenic substances may cause deficiency.	Iodized salt, trace mineralized salt, and ethylenediamine dihydroiodide (EDDI).
Iron (Fe)	Part of hemoglobin; part of many enzymes.	Nutritional anemia.	Forages; grains; and commercial supplements.
Copper (Cu)	Needed for production of hemoglobin; part of several enzymes.	Severe diarrhea; abnormal appetite; poor growth; coarse, graying hair coat; osteomalacia.	Trace mineralized salt and commercial supplements.

(*Continued*)

Table 2.5. (*Continued*)

Mineral	Functions	Deficiency symptoms	Common feed sources
Cobalt (Co)	Part of vitamin B12; needed for growth of rumen microorganisms.	Failure of appetite; anemia; decreased milk production; rough hair coat.	Trace mineralized salt and commercial supplements.
Manganese (Mn)	Growth; bone formation; enzyme activator.	Delayed or decreased signs of estrus; poor conception.	Trace mineralized salt and commercial supplements.
Zinc (Zn)	Enzyme activator; wound healing.	Decreased weight gains; lowered feed efficiency; skin problems; slow healing wounds.	Forages; trace mineralized salt, commercial supplements, and zinc methionine.
Selenium (Se)	Functions with certain enzymes; associated with vitamin E; maintenance of the immune system.	White muscle disease in calves; retained fetal membranes; improve reproductive performance; lessen subclinical mastitis.	Oil meals; alfalfa; wheat; oats; corn; commercial supplements.
Molybdenum (Mo)	Part of the enzyme xanthine oxidase.	Loss of weight; emaciation; diarrhea.	Widely distributed in feeds; deficiency is rarely a problem.

Source: University of Minnesota. www.extension.umn.edu/distribution/livestocksystems/components/DI0469t02-05.html#t04.

enhance level and efficiency of performance and health, and to improve the level of production and environment. Additives are a complement to good feed management and should not replace a poor nutrition program. They are effective tools to harmonize and improve the transition program. They can be classified as rumen or metabolic modifiers. Within rumen modifiers, the following products are available: direct-fed microbials (DFM), ionophores (monensin, lasalocid), buffers (sodium bicarbonate, magnesium oxide), enzymes, organic acids, saponins (extract of quillay and yucca), and essential oils. Within metabolic modifiers, the following products are available: glucose precursors (calcium propionate, ionophores, propylene glycol, glycerol), anionic salts to prevent hypocalcemia, organic minerals (Se, Zn, Cu, Co, Mn), vitamins (niacin, biotin, protected choline), methyl donors (methionine hydroxyl analog), and protected amino acids (lysine, methionine), as shown in Table 2.2.

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3

Calving Management: A Team Approach

Maarten Drost

Abstract

On commercial dairy farms, nearly 50% of the heifers and 30% of the cows require obstetrical assistance. Frequent monitoring to detect delays in progress is essential. Early intervention prevents calf losses and protects subsequent fertility of the dam. The veterinarian should train personnel on the farm and provide them with protocols and guidelines for proper calving assistance procedures. This chapter provides guidelines to allow veterinarians to design a herd health protocol that emphasizes first-aid calving assistance to encourage producers to use proper calf-delivering techniques.

Introduction

Calving management has traditionally been approached in a passive manner. On large dairy farms, the attendant veterinarian cannot personally monitor all obstetrical problems. The 24-h-a-day, 7 days-a-week supervision and care of the calving pen is generally delegated to employees with varying degrees of knowledge and skills in obstetrics. A secondary problem is that calving difficulties rarely occur at a predictable or convenient time, that is, when there is enough help. Unfortunately, both haste and delays lead to injuries to the calf or the dam, or both. A first line of defense is important because early intervention not only prevents calf losses but also protects the subsequent fertility of the dam.

In a study of 7350 calvings that produced 7780 calves on three Colorado dairy farms, it was reported that 51.2% of first calf heifers required assistance, and 29.4% of the pluriparous cows, while the percentage of stillborn calves was 8.2% overall (Lombard et al., 2007). The authors also showed that the risk for health and survival of dairy calves was greater for bull calves versus heifer calves, for twins versus singletons, and for calves involved in a dystocia versus those born by spontaneous delivery.

The solution on large dairy farms is to develop a calving management program. On-farm personnel should know what to look for and how to assess what level of assistance might be required. It is important that a team be trained and provided with a protocol and a designated facility equipped with obstetrical supplies. The aim of this chapter is to provide the veterinarian, as coach of the team, with an outline of the highlights of basic knowledge, procedures, and guidelines for intervention in early obstetrical care, and instructions as to when he or she should be called for advanced diagnosis and resolution of dystocias. Pictures of the various procedures, instruments, and anatomical relationships are shown in this chapter and can also be viewed in the Bovine Reproduction Guide (Drost, 2000; drostproject.org).

Calving Facilities

Ideally, cows should calve on grass in a clean pasture that is free from standing water and that has shade. The pasture should also be close enough to permit regular and easy supervision. Furthermore, it must be easy to take the cow or heifer to a calving stanchion for close examination and assistance. This working area should provide protection from the weather and must have

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running water and a cabinet for instruments and supplies. A maternity bam with well-bedded individual pens is a good alternative to a calving pasture, but the pens must be cleaned thoroughly between each use. A head gate with hinged side panels that swing away from the back end of the cow is ideal. There must be room for the cow to lie down plus room for the assistants to work behind the cow.

Signs of Calving

Progressive udder development is one of the earliest signs of the approach of calving. Early enlargement occurs in heifers during the fourth month of pregnancy. In cows, enlargement of the udder may not become apparent until 2–3 weeks before calving. Just prior to the onset of calving, the udder secretion changes from a sticky serum-like substance to colostrum, a thick yellowish-opaque secretion. It is common to see udder edema in heifers that are ready to calve. The edema is due to the accumulation of tissue fluid in front of the udder around the navel, and at the rear attachment of the udder. Finally, the teats become turgid and lose their wrinkles. The lips of the vulva also become larger and softer, and lose their wrinkles.

At the same time the ligaments that connect the various bones of the pelvis begin to relax, giving the cow a somewhat unsteady gait. As the pelvic ligaments relax, the tail head appears to become slightly raised. The onset of progressive relaxation of the ligaments coincides with the onset of softening and dilation of the cervix. Complete relaxation of the posterior border of the pelvic ligaments, the so-called bands, is generally followed by delivery within 12 h.

Signs of discomfort and restlessness do not usually appear until the cervix has dilated sufficiently to admit a hand. Slight arching of the back is apparent at this time, but definite straining (the abdominal press) does not begin until the first water bag (chorioallantois) nears the vulva. Hydrostatic pressure by the fetal fluids contained within the intact membranes assists in complete dilation of the cervix. Stretching of the vagina causes reflex contractions of the abdominal muscles, and during one of these contractions the first water bag ruptures. Following rupture of this membrane, there is a temporary weakening or cessation of straining, which resumes as the second water bag (amnion) nears the vulva. The thick, slippery, slimy fluid contained in this bag provides lubrication for the delivery once it ruptures. The average interval between rupture of the first and the second water bag is about 1 h.

Once the amniotic sac has burst, regular intermittent straining begins after a brief period of rest. As a labor progresses, there is a gradual increase in the frequency and duration of the abdominal contractions, and straining sometimes becomes nearly continuous during the last few minutes before calving. The presence of the legs also contributes to reflex straining during this stage of labor. The greatest delay in expulsion of the calf occurs when the head reaches the vulva. At this stage little outward progression takes place during each series of contractions, and the calf frequently slips back into the vagina between bouts. This feature is most obvious in heifers, in which stretching of the vulva takes more time. Once the head of the calf has passed through the vulva, the rest of the body follows rapidly. During hot and humid weather, cows can become easily exhausted and frequently give up. These heifers and cows require early assistance while the birth canal is fully dilated.

Calving Problems

The most common cause of difficult calving is fetal–maternal disproportion: a calf that is too big and/or a pelvis that is too small. Other fetal causes are abnormal posture of the calf (the head or a leg retained), twins, and occasionally fetal monsters. Maternal causes include hydrallantois, hydramnios, torsion of the uterus, and rupture of the prepubic tendon.

Calving Assistance

The minimum supplies needed to provide assistance at the time of calving are a ready supply of clean water, two buckets, soap, lubricant, two obstetrical chains plus handles, oxytocin, and 7% tincture of iodine. When there has been no visible progress for 2 h after the appearance of the membranes, the cow should be examined to determine the cause for the delay as well as the type of assistance she may need. Heifers are slower to dilate and should be given more time than cows; however, there should be evidence of progress. The calf will often live for 8–10 h in the uterus after the beginning of true labor that begins with the rupture of the first water bag.

The golden rules of obstetrics are *cleanliness* and *lubrication*. Before the cow is examined internally, the tail should be tied to her neck, and the anus, vulva, and the pin bones should be washed thoroughly with soap and water. Next, the hands and arms of the person assisting should be washed with soap and water, and lubricated. Soap or detergents must not be used as lubricants because they defat and remove the natural lubrication from the walls of the birth canal. Mineral oil and Vaseline make very good, lasting lubricants, as does Crisco oil. They should be frequently reapplied to the arms and hands during repeated entries into the birth canal.

It takes from 2 to 6 h for the cervix to completely dilate in the average cow, and from 4 to 10 h in the average heifer. The actual expulsion of the calf takes from 1 to 4 h in the cow and from 2 to 6 h in the heifer. The fetal

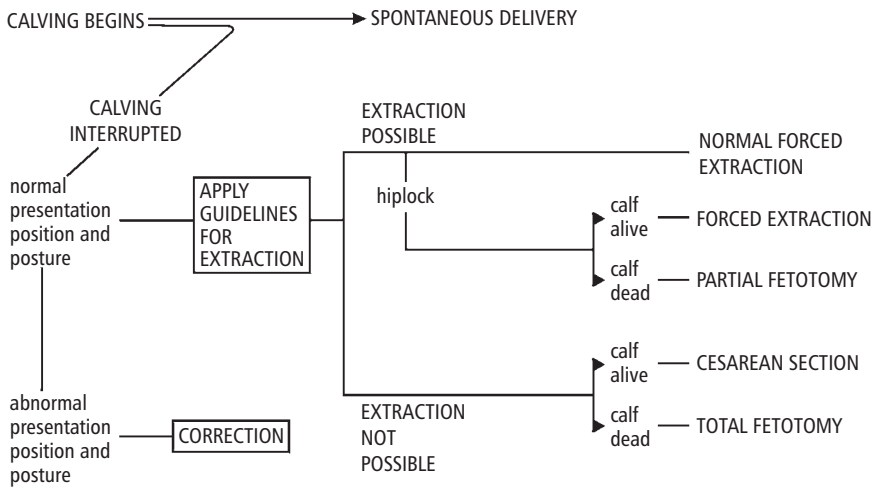

Figure 3.1. Decision tree in providing calving assistance.

membranes (afterbirth) are normally delivered from 1 to 8 h. They are considered retained if not delivered within 12 h.

Examination

It is important to follow a plan for determining how to deliver a calf (Schuijt & Ball, 1980), as shown in Figure 3.1. The first step is to thoroughly wash the cow as well as the hands and arms of the examiner with soap and water; the next step is to use ample lubrication. The internal examination is aimed at determining whether the calf is presented head first (cranial presentation) or tail-first (caudal presentation) and whether the head and neck and both limbs are present and fully extended. At the same time, it is decided whether or not the calf is alive. If the head is accessible, a swallowing or gagging reflex can be stimulated by sticking a couple of fingers into the mouth. Pushing the claws of one foot apart causes the calf to pull its foot back, unless it is jammed too tightly in the birth canal, leading to a false negative response. Third, pushing on the eyeball makes live calves blink. When a calf is in a caudal presentation, the claw reflex can also be used, with the same limitations. Alternatively, the pulse can frequently be felt in the umbilical cord by reaching along the belly of the calf. Finally, inserting a finger in the anus will elicit a puckering reflex in a live calf. If the head and neck are turned back along the side of the calf, the abnormal posture must first be corrected before the calf can be extracted. Abnormal posture is most common in calves that are weak or dead, or extremely large. Correction is generally made by pushing the entire calf back into the abdomen of the cow to make room for manipulation and retrieval of the retained part. It will depend on the experience of the operator and the degree of retention whether the help of a veterinarian is needed at this time. There is no extreme urgency to immediately pull the calf. In fact, it will save time and reduce stress on the calf to first properly prepare the dam. Finally, the decision must be made as to whether there is sufficient room for the calf to be delivered.

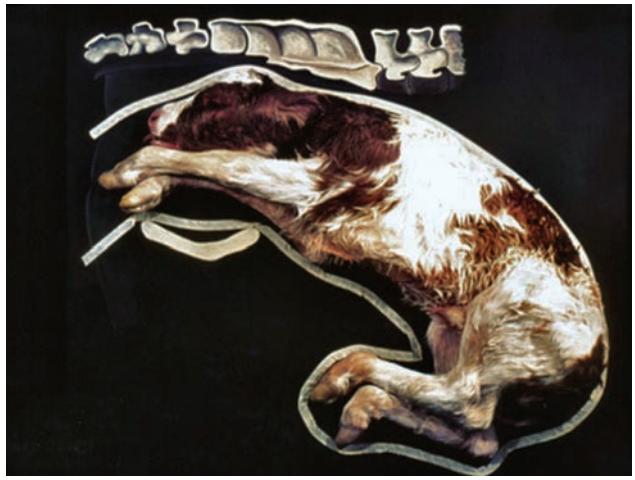

Figure 3.2. Calf is in anterior longitudinal presentation (head first), dorsosacral position (right side up), and has normal posture (both limbs and head and neck extended).

Guidelines to Determine if There Is Room

The following guidelines are those developed at the obstetrical clinic of Utrecht University, the Netherlands, to determine whether or not vaginal delivery of the calf is possible (Schuijt & Ball, 1980).

Anterior presentation (head first) is shown in Figure 3.2. The entire head resting on the knees and both feet must be presented into the birth canal. Chains are looped around each foot just below the dewclaws with the large link on top so the pull comes off the dorsal surface. There will be sufficient room to pull the calf, if one person can pull the first leg until the pastern is 15 cm

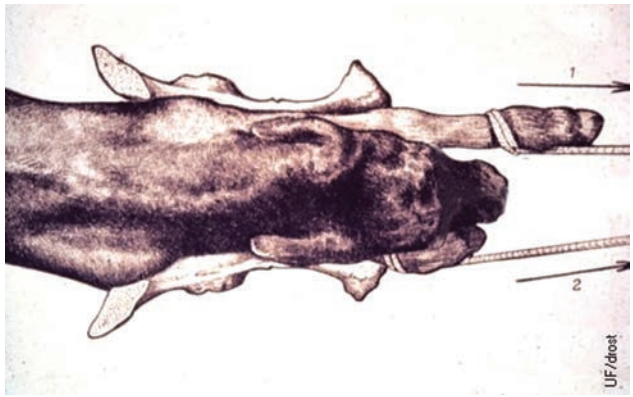

Figure 3.3. The calf is in anterior longitudinal presentation, dorsosacral position, with normal posture. One leg is pulled by one person until the pastern is 15 cm outside the vulva. This means that the point of the shoulder has passed the iliac shaft. It is held there. If the second leg can be pulled equally far (again by one person) outside the vulva, both shoulders will have passed the iliac shafts of the pelvis and the narrowest portion of the birth canal. Since the pectoral girdle is the greatest diameter of the calf, the entire calf can now be delivered per vaginam by traction, while rotating the calf to accommodate the hips of the calf.

outside the vulva and, next, while holding the first leg in this position, if again one person can pull the second leg equally far outside the vulva (Fig. 3.3). At these distances, both shoulders of the calf will have passed the bony entrance of the pelvis. The diameter of the calf is greatest at the points of the shoulders.

Posterior presentation (backward) is shown in Figure 3.4. Five percent of the time, calves are born backward (Roberts, 1986). This presents two problems: the blunt-shaped hindquarters are less efficient in dilating the birth canal than the cone-shaped head and neck, and the umbilical cord becomes compressed against the pelvic inlet while the head is still inside the dam. Again, chains are looped around each foot below the dewclaws with the large link at the front of the foot so the pull comes off its dorsal surface. If, with the cow lying on her side, it is possible for two people to pull both hocks on a rotated calf far enough for the hocks to appear at the lips of the vulva, then it will be possible to deliver the intact calf by way of the vagina.

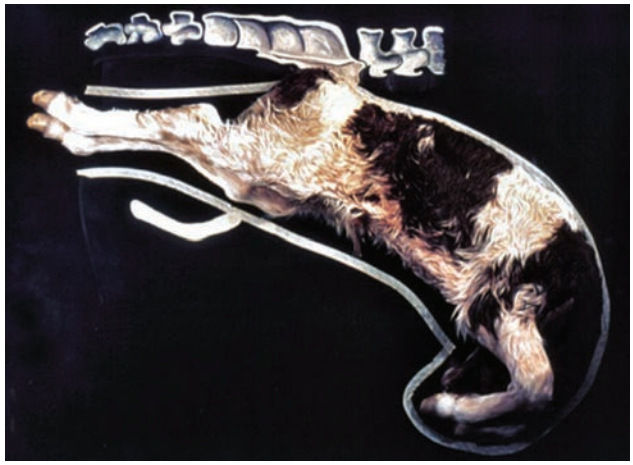

Figure 3.4. This calf is in a posterior longitudinal presentation (backward), dorsosacral position, and normal posture (both legs extended).

Preparation of the Cow for Pulling the Calf

While the cow is still standing, she should again be washed with soap and water, and the degree of dilation of the soft tissues of the birth canal should be evaluated. With folded fingers, both well-lubricated arms are inserted into the vulva and vagina like a wedge as shown in Figure 3.5. Next the tissues are stretched by pushing the elbows outward. It may take up to 20 min for some heifers to fully dilate the vulva and the vulvo-vaginal sphincter. The preparation will not only minimize tearing, but it will also speed delivery once the process

Figure 3.5. After it has been determined that there is enough room for the calf to be delivered per vaginam, it is helpful to stretch the lips of the vulva, especially in heifers. With the heifer standing, the forearms are inserted halfway to the elbows. Next, with the fingers folded, the arms are wedged apart in the direction from 11 o'clock to 5 o'clock and alternately from 7 o'clock to 1 o'clock, for 10 or more repetitions. After this the heifer is cast and the calf is extracted.

Figure 3.6. After it has been determined that there is enough room for the calf to be delivered per vaginam, the cow is cast in (preferably) right lateral recumbency. This (1) allows the hind legs of the dam to angle forward, which enlarges the operative diameter of the pelvis; (2) lets the heifer slightly spread her legs and stretch the cartilaginous symphysis pubis; (3) aids the calf in coming through the birth canal in a plane parallel to the ground, versus having to rise from the bottom of the abdomen—against the force of gravity—to enter the pelvic inlet; (4) virtually all cows go down during the second stage of parturition, hence it is better to cast them in a preselected location with sufficient room behind the cow to assist her.

of extraction is started. Next the cow is cast as shown in Figure 3.6. She can be laid down by tying her head low to the ground to a post and by tying a long rope around her neck with a nonslip knot and then by placing two half hitches around her body. The first half hitch is placed tightly just behind the front legs, the second just in front of the hind legs and in front of the udder. By pulling on the free end of the rope straight behind the cow, she will be made to lie down and can then be rolled onto her right side. The advantages of casting her are that she can angle her pelvis more favorably by bringing her legs forward; the people pulling can sit on the ground and exert more pull; the calf does not have to come up out of the abdomen against the force of gravity; and she does not lie down unexpectedly in the middle of the extraction process, in an awkward location.

Rotation of the Calf

A cross-section of the entrance into the bony pelvis (pelvic inlet) of the cow is shaped like that of an egg with

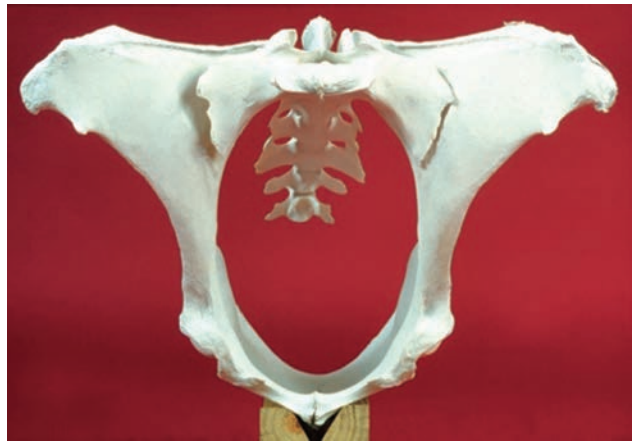

Figure 3.7. The diameter of the bovine pelvis is oval whereby the vertical diameter is greater than the horizontal diameter. In addition, the dorsal horizontal diameter is somewhat greater than the ventral one.

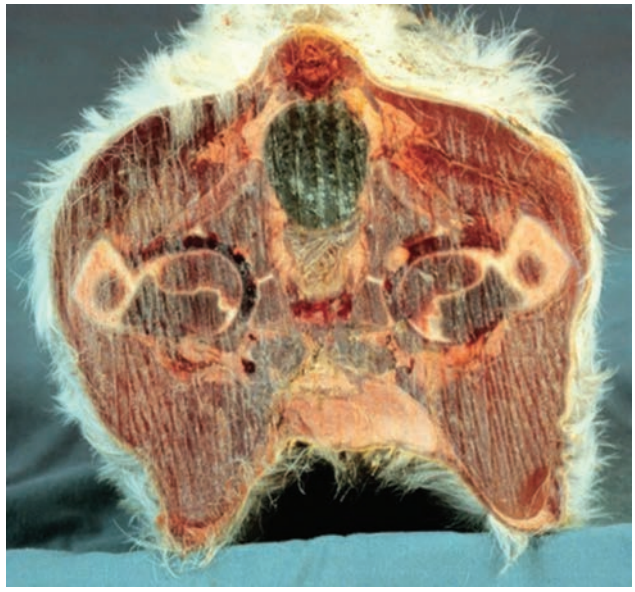

Figure 3.8. The cross section of the fetus at the level of the hips, through the greater trochanters, is wider (horizontally) than it is tall (vertically). This is just opposite to that of the pelvis of the cow.

the small end down (shown in Fig. 3.7). This means that the opening is taller than it is wide, and wider near the top than near the bottom. On cross section, the pelvis of the calf is wider at the hip joints (which are located below the tubera coxarum or hooks), than it is tall, as shown in Figure 3.8. Therefore, rotation of the calf allows its widest portion (the hips) to come through the greatest diameter of the pelvic inlet. However, the calf must be rotated before its hips contact the pelvic inlet, as shown in Figures 3.9 and 3.10. The operator positions himself or herself on his or her knees next to the rear legs and udder of the cow. For a calf in cranial presentation, rotation is started as soon as the head is outside the

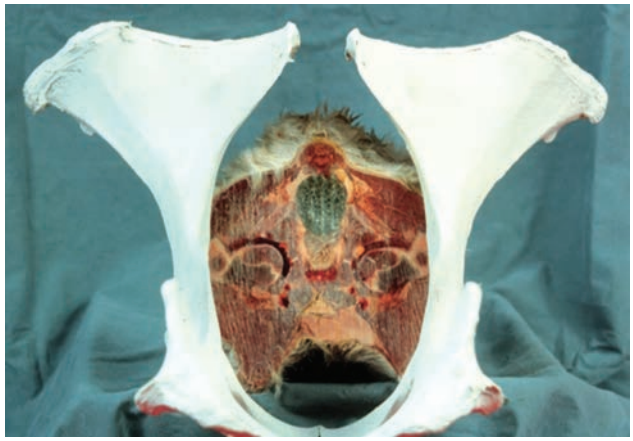

Figure 3.9. The width of the hips of this large calf is wider than that of the pelvic inlet. Note that the greater trochanters are hidden laterally behind the iliac shafts.

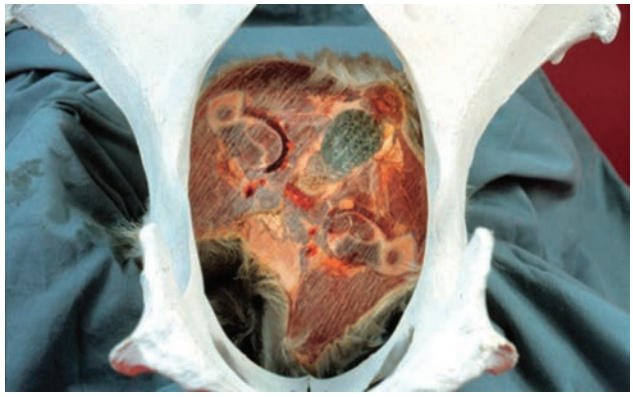

Figure 3.10. To prevent hiplock, the fetus should be rotated as it enters the pelvic inlet, allowing the greater trochanters more space.

vulva. The operator passes his or her arm nearest the cow between the legs of the calf and above the neck. The other hand and arm are passed completely underneath the calf, and the fingers are locked near the base of the neck as shown in Figure 3.11. The head can then be pulled toward the knees of the operator, who rotates the calf while traction is applied.

When the calf is in posterior presentation, rotation must be started as soon as the operator has access to the legs, that is, before the fetal hips have entered the pelvic inlet. Again the cow is cast on her right side. Everything should be ready before the final pulling is started because once the umbilical cord is pinched, the oxygen supply to the calf is shut off. Handles should be attached close to the calf so they need not be moved when the calf is halfway out of the cow. Once the hips of the calf have passed the pelvic inlet, the back of the calf is rotated back to line up with the back of the cow, and the calf is pulled in a direction parallel to the hind legs of the cow.

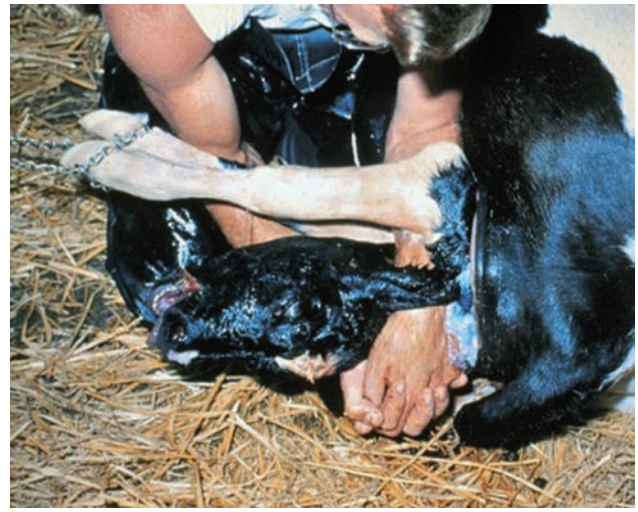

Figure 3.11. Rotation is started as soon as the head of the calf is out. The obstetrician places one arm all the way under the calf and inserts the other arm between the legs. The fingers are then folded and the head is pulled toward the knees when traction is applied in synchrony with the expulsive efforts of the cow.

All pulling is done intermittently and only while the cow strains, upon command of the operator. This allows the cow, the calf, and the assistants brief periods of rest before the next maximum effort. The only exception to this rule is when the hips of a calf that is coming backward have just come through the vulva. These calves cannot breathe because the head is still in the uterus and the oxygen supply via the umbilical cord has been cut off. Continuous traction is applied until such a calf has been delivered.

Care of the Calf Immediately After Delivery

Delayed passage through the birth canal in the face of a faltering placenta compromises oxygenation of the calf. Although the calf is able to breathe as soon as its nose passes the lips of the vulva, expansion of its chest is restricted by the narrow birth canal. This situation is made much worse when continuous forced traction is applied. As soon as the head of the calf has passed the lips of the vulva, traction should be interrupted, the nostrils cleared of mucus, and cold water applied to its head.

Again, when the calf is completely delivered, immediate attention is directed toward establishing respiration. Mucus and fetal fluids should be expressed from the nose and mouth by external pressure of the thumbs along the bridge of the nose and the fingers flat underneath the jaws, sliding from the level of the eyes toward the muzzle. The calf should be placed in sternal recumbency as in Figure 3.12. The common practice of suspending the calf by the hind legs as shown in Figure 3.13

Figure 3.12. As soon as the calf has been delivered, the immediate concern is that it is breathing. It is best to place the calf in sternal recumbency to allow both sides of the chest to expand.

to "clear the lungs" must be questioned. Most of the fluids that drain from the mouth in these calves come from the stomach, and the weight of the intestines on the diaphragm makes expansion of the lungs difficult. The most effective way to clear the airways is by suction.

Respiration is stimulated by many factors, but only ventilation of the lungs, cooling, and certain drugs allow us to render help immediately. The best stimulus for respiration is ventilation of the lungs. Cooling is an important respiratory stimulus that can be achieved by simply pouring cold water over the head of the calf. Cold water elicits the gasp reflex that aids in the expansion of the lungs. Brisk rubbing of the skin or tickling inside the nostril with a piece of straw also has a favorable effect. The phrenic nerve can be stimulated with a sharp tap on the chest slightly above and behind where the heartbeat can be felt.

Artificial Respiration

The calf is placed on its side and the mouth and nostrils are cleared of mucus. An assistant holds the mouth open and extends the tongue of the calf to allow air to pass freely. While kneeling behind the chest of the calf, the operator uses one hand to grasp the upper part of the top front leg, while the fingers of the other hand are hooked underneath the last rib. Next, the chest wall is elevated by lifting the front leg and the edge of the rib cage until the calf is almost lifted off the ground; this expands the chest. During a short pause, the lungs are given the opportunity to expand. This expansion is slow because the lungs are still "wet," never having been inflated. Next, the chest walls are firmly compressed with flat hands. These movements are repeated approximately once every 5 s, whereby the major effort is aimed at the inspiration.

As a rule, no expiratory sound will be heard until after several resuscitative movements. Initially, very little air will be aspirated as the lungs begin to expand. This treatment may be maintained for 15 min while other methods to stimulate respiration are employed, such as cold water or drugs. When spontaneous respiratory movements occur after a few minutes, they are immediately supported, after which the rhythm of the artificial respiration is resumed.

Figure 3.13. While a common practice among lay people, suspending the calf by the hind legs is not recommended. In doing so, the full weight of the viscera is on the diaphragm of the calf and compresses the lungs. This makes it more difficult rather than easier for the calf to breathe (expand its lungs). There is no fluid in the lungs of the newborn calf, they are consolidated (atelectatic) prior to the first breath. There is a small amount of mucus in the trachea and the nostrils. The latter can be squeezed by stripping the nasal passages from the eyes toward the nostrils. Mucus seen running from the mouth and nose of the suspended calf is actually amniotic fluid coming from the stomach. (Meconium staining denotes intrauterine hypoxia.)

The major advantage of this prompt intervention is that the lungs are immediately supplied with oxygen. In addition, the heart is massaged, and a pumping action is exerted on the large vessels of the heart, stimulating circulation.

After the frequency and depth of spontaneous respiration have reached an adequate level, the calf is briskly rubbed dry. The calf is then placed on its chest with the front legs extended and spread out and the hind legs in

a dog-sitting position extended alongside the body; this facilitates expansion of the chest. A handful of straw may be placed in each of the armpits to keep a weak calf from falling over.

Once respiration has been established, the umbilical stump is disinfected and dried by submersion in a clean cup of 7% tincture of iodine.

Care of the Dam After Delivery

After respiration has been initiated in the calf, the dam should be examined for the presence of another calf and for possible trauma to the birth canal, such as tears of the cervix, the vaginal wall, and the vulva.

Colostrum

Early ingestion of colostrum is essential for the newborn calf. The protective effects associated with the transfer of colostral immunoglobulins (Igs) have been demonstrated repeatedly, both in the field and experimentally. The composition of colostrum changes rapidly to that of normal milk during the first 3 days of lactation.

The calf should receive at least 8% of its body weight in colostrum within 12 h after birth; 2 L within the first 2 h. If the calf is reluctant to nurse, the colostrum should be given by esophageal feeder or stomach tube. Slightly bloody colostrum can safely be fed to calves if it is otherwise normal. Grossly abnormal colostrum, such as from a cow with acute mastitis, must be discarded. Providing adequate amounts of colostrum will not necessarily prevent diarrhea, but it will aid in the prevention of subsequent septicemia and decrease mortality. Igs are absorbed from the intestine for only a short time after birth, and the efficiency of absorption decreases linearly with time. Furthermore, "shutdown" of absorption is different for each class of Igs. IgG can be absorbed for 27 h and IgA for 22 h, but IgM is absorbed for only 16 h. Thus, a calf that nurses for the first time at 10–12 h of age could still acquire high levels of IgG and IgA, but little IgM. As a consequence, such calves are very susceptible to colibacillosis.

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4

Monitoring Health and Looking for Sick Cows

Carlos A. Risco and Mauricio Benzaquen

Abstract

A major goal for transition cow management is to keep a dairy cow healthy during early postpartum (the first 3 weeks after calving). Monitoring postpartum health involves the examination of cows in early postpartum by trained farm personnel using health parameters to identify sick cows and provide treatment. Veterinarians have an opportunity to expand their services to dairy producers by implementing training programs for farm employees to look for sick cows using time-effective techniques to identify animals in the early stages of disease and allow for routine treatment.

Introduction

An important concept in dairy herd health is the early diagnosis and treatment of sick cows. It may even be more important than the type of treatment administered. A delay in treating a sick cow not only reduces her chances for a full recovery but results in milk production loss and may impair reproductive performance, especially if the disease occurs in early postpartum. Although we have made strides in transition cow management, on many dairy farms we fail to find a sick cow early in her disease course, which leads to a delay in treatment. Furthermore, there are different opinions on health monitoring strategies, which health parameters to use, and how to implement them. This chapter discusses parameters that can be used to monitor postpartum health and how they can be used to find sick cows.

Monitoring Postpartum Health

The premise for monitoring postpartum health in cows is to identify any change that occurs from what is considered a normal state. These programs are implemented on farms to identify sick cows early and provide supportive therapy and improve animal well-being. Additionally, they are implemented to prevent diseases; a cow diagnosed with metritis and treated can help prevent the development of ketosis and displaced abomasum. Monitoring postpartum health involves the evaluation of cows by trained farm personnel during the early postpartum period (7–14 days after calving) by evaluating health parameters to identify sick cows followed by a physical examination to make a disease (metritis, ketosis, displaced abomasums, and mastitis) diagnosis and provide treatment (Upham, 1996). Food animal veterinarians play a major role in these programs, and their primary role on many dairy farms is no longer to identify and treat sick cows but to develop, implement, and supervise the application of these programs.

Health parameters that can be used include rectal temperature, attitude, milk production, uterine discharge, and presence of ketone bodies in blood, milk, or urine. A common problem observed on many dairy farms, when monitoring postpartum health, is that too much emphasis is given to one or two of these parameters. It is important to instruct farm personnel involved in health monitoring that the combination of these parameters must be considered when making a

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decision as to whether or not a cow is sick and requires treatment.

Rectal Temperature

The premise for evaluating rectal temperature postpartum is that an elevated temperature indicates an abnormal health status. More specifically, in postpartum dairy cows, an elevated temperature most likely indicates a metritis, mastitis, or pneumonia. Monitoring rectal temperatures will result in a wide range of values from individual cows. The normal rectal temperature range for cattle is from 38.6 to 39.4°C, where a fever is diagnosed when the temperature is >39.4°C (Smith & Risco, 2005). The variation in rectal temperature is influenced by factors such as health status, age, season of year, and time of day.

Although an individual cow's body temperature will vary, a healthy cow maintains a narrow range. Kristula et al. (2001) reported that cows experiencing no clinical problems at calving or during early postpartum had an average rectal temperature below 38.8°C for each day during the first 10 days postpartum. However, cows with metritis (fetid vaginal discharge and a depressed attitude) may present with rectal temperatures within the normal range and may not necessarily develop fever. Benzaquen et al. (2007) evaluated daily rectal temperature and attitude to monitor postpartum health and found that over half of the cows diagnosed with metritis during the first week postpartum did not have fever, defined as a rectal temperature >39.4°C.

Cows with an abnormal parturition had rectal temperatures >39.5°C related to metritis for significantly more days than cows that calved normally (Kristula et al., 2001). Furthermore, Benzaquen et al. (2007) reported that cows with an abnormal calving had a higher incidence of metritis when compared with cows with a normal calving. From these studies, it can be concluded that cows with an abnormal calving (dystocia, retained placenta, or twins) should be monitored carefully early postpartum.

Several studies have shown the successful use of antibiotics in cattle with elevated rectal temperatures related to metritis. Kristula et al. (2001) reported a significant (0.5°C) drop in temperature in cattle 24 h after the initial treatment with antibiotics. Smith et al. (1998) also showed similar findings where cows identified with toxic puerperal metritis and treated with antibiotics responded with a significant decrease in temperature the following day. From these studies, it is prudent to conclude that dairy cows diagnosed with fever due to metritis during early postpartum respond positively to antimicrobial treatment.

The challenge in the employment of health monitoring programs is to decide when to treat cows. The study cited earlier (Kristula et al., 2001) found that abnormal cows had their highest average temperatures on days 3 through 6, and 66% of all cows treated were between 2 and 5 days postpartum. Similar results were obtained by Benzaquen et al. (2007). These findings indicate that the majority of cows develop fever related to uterine infection within 1 week after calving. Therefore, monitoring programs using rectal temperature should be put in place for at least 7 days after calving.

Attitude

It is imperative that farm managers, along with their veterinarians, identify farm employees with the interest and ability to look for sick cows. They should be taught to look at the eyes, ears, presence of uterine discharge, and overall demeanor. Positioning and appearance of the eyes within the socket to access level of dehydration or pain can be observed and scored. A scoring system such as 1 (minimal), 2 (mild), 3 (moderate), or 4 (severe) can be used (Smith & Risco, 2005). A cow with a score of 1 usually will have bright eyes that are positioned normally within the eye socket. A score of 2 will have dull eyes that are slightly sunken (1–2 mm) within the eye socket. A score of 3 will have glazed eyes that are moderately sunken (2–4 mm), whereas a score of 4 will have dry eyes that are severely sunken (>5 mm) within the eye socket. The positioning of the cow's ears is also a good indicator of a cow's attitude. Sick cows usually have ears that droop down due to depression, pain, fever, or dehydration. Healthy cows, on the other hand, appear bright and alert and are curious about their environment. Upon being approached, a healthy cow will often try to make contact with its nose and tongue.

In farms that have locking stanchions, the attitude of the cow can be observed after feeding to evaluate appetite. A cow that is sick will not eat; conversely, a healthy cow willingly eats her feed. A cow's appetite can be evaluated according to this scoring system: (1) cows that lock and eat, (2) cows that lock, appear dull, and do not eat, and (3) cows that do not lock to eat and appear dull or sick (Smith & Risco, 2005). Cows that fall in categories 2 or 3 should be monitored or examined carefully.

Milk Production and Walking Activity

Daily milk production is monitored on many farms using computerized milking machines. Milk production values are related to the health of a cow. As mentioned earlier, a sick cow does not eat, and consequently, her milk production drops. Dairy cows with a normal postpartum period have a steady, progressive, day-to-

day increase in milk production. Determining the deviation value to identify sick cows varies between farms. Some managers create a list of all cows that deviate from a value equal to or more than a preset value. In most dairies, a 5-kg drop in production is frequently used. Trained employees will use this deviation list to identify these cows and perform a thorough physical examination.

Advancement in technology has made monitoring of walking activity and milk production on dairy farms feasible. Edwards et al. (2004) evaluated whether daily walking activity and milk yield could be used as predictors of metabolic and digestive disorders early in lactation. Walking activity and milk production were recorded from the Special Agricultural Equipment Afikim® computerized dairy management system (Kibbutz Afikim®, Israel). Metabolic disorders were ketosis, retained fetal membranes, and milk fever. Digestive disorders included left displaced abomasum, indigestion, reduced feed intake, traumatic gastritis, acidosis, and bloat. Walking activity was generally lower among sick cows, and daily milk yields of sick cows were approximately 15 kg/day less than milk yields of healthy cows. Milk yields started to drop in affected cows 5–7 days prior to disorder diagnosis. Results from this study indicate that changes in walking activity and daily milk yield are useful tools to detect transition cow disorders early in the disease process.

Uterine Discharge

Metritis is a common disease during the postpartum period, and it is commonly identified using a health monitoring program. Cows with metritis appear sick and have a fetid discharge with fever (>39.4°C; Sheldon et al., 2009). However, as previously mentioned, a study that evaluated daily rectal temperature distinguished cows with metritis with or without fever, indicating that this condition may not always be accompanied by fever (Benzaquen et al., 2007). This finding suggests that diagnostic and treatment consideration for metritis should include vaginal discharge and cow attitude, not rectal temperature alone. A discharge that is red-brown and contains mucus that is not fetid should be considered normal (lochia). A watery, foul-smelling discharge more often indicates a severe form of metritis that needs therapy as opposed to a mucoid, nonfetid discharge which more often indicates a recovering situation.

A common method used to evaluate uterine discharge is palpation of the uterus and visual inspection of the vulva for a malodorous, brownish-colored discharge. However, this method of diagnosis is often inconsistent in its ability to produce and evaluate the discharge outside of the cow. Consequently, the use of vaginoscopy to visualize discharge deep in the vagina can be used. Alternatively, insertion of a clean gloved hand into the vagina and extension of it to the cervix to gather vaginal content can be used to characterize discharge type after the hand is removed from the vagina. Furthermore, a device consisting of a stainless steel rod with a rubber hemisphere (Metricheck™, Simcro, New Zealand) can be introduced aseptically deep into the vagina to retrieve and evaluate vaginal discharge.

Ketones in Milk or Urine

Ketone bodies in blood, urine, or milk can be used to diagnose subclinical ketosis in lactating dairy cows. Evaluation of subclinical ketosis in postpartum dairy cows is a valuable health parameter that should be used more frequently to diagnose sick cows. The cost of subclinical ketosis per cow is estimated to be $78 (Geishauser et al., 2001). Ketosis has been associated with an increased risk for cows to develop metritis (Markusfeld, 1984, 1987; Reist et al., 2003), displaced abomasum (Geishauser et al., 1997), and mastitis (Syvajarvi et al., 1986). A negative impact on milk production may also occur, and it has been reported that cows that produce a positive milk ketone test produce 1.0–1.4 kg less milk per day for the lactation (Geishauser et al., 1997). Identification and treatment of cattle suffering from subclinical ketosis in the immediate postpartum period could reduce the negative side effects of ketosis.

A value of 1400 μmol/L of beta hydroxy butyrate (BHBA) or greater in blood has been established to differentiate cows with and without subclinical ketosis. Several cowside diagnostic tests (dipsticks, powders, tablets) are commercially available. These tests determine acetoacetate and, to a lesser degree, acetone in urine (Ketostix® strip, Bayer, Leverkusen, Germany) or BHBA in milk (e.g., Ketolac®, Biolab, München, Germany) based on the degree of color change. A study by Carrier et al. (2004) evaluated the performance of three cowside tests for detection of subclinical ketosis. The tests evaluated were a commonly used powder for detecting milk acetoacetate (Keto Check®, Great States Animal Health, St. Joseph, MO), a urine strip detecting ketones acetoacetate in urine (Ketostix®, Bayer Corporation, Elkhart, IN), and a milk test strip for ketone bodies (BHBA). The study concluded that either the Ketostix or KetoTest® strips would provide acceptable results for screening individual cows on commercial dairies to detect ketosis and the KetoCheck would have limited application. Electronic handheld blood glucose and ketone measuring systems are commercially available to veterinarians and surpass the predictive value of

Table 4.1. Performance of three cowside diagnostic tests for detection of subclinical ketosis defined as BHBA serum concentrations ≥ 1400 μmol/L.

Tests[1]	Substrate	Threshold (1400 μmol/L)	Tests (n)[2]	Se (%) (CI_{95})	Sp (%) (CI_{95})	+PV (CI_{95})	–PV (CI_{95})
Precision Xtra	Blood	1400	196	100 (69–100)	100 (94–100)	100 (69–100)	100 (98–100)
Ketolac	Milk	100	194	90 (56–100)	94 (90–97)	45 (23–68)	99 (97–100)
Ketostix	Urine	4000	186	67 (30–93)	100 (98–100)	100 (54–100)	98 (95–100)

[1] Precision Xtra from Abbot Diabetes Care (Abingdon, UK); Ketostix from Bayer (Leverkusen, Germany); and Ketolac from Biolab (München, Germany).
[2] Number of observations paired with a serum BHBA measurement for each cowside test.
Se = Sensitivity: proportion of diseased (subclinical ketosis) cows that test positive; Sp = specificity: proportion of nondiseased cows that test negative; +PV = positive predictive value: proportion of cows with a positive test that are diseased; –PV = negative predictive value: proportion of cows with a negative test that are not diseased; CI_{95} = 95% confidence interval.
Source: Adapted from Iwersen et al. (2009).

the previously mentioned cowside tests to diagnose subclinical ketosis (Iwersen et al., 2009). Performance of cowside diagnostic tests for detection of subclinical ketosis is shown in Table 4.1.

In the study by Iwersen et al. (2009), the authors concluded that electronic handheld BHBA measuring system using whole blood is a useful and practical tool to diagnose subclinical ketosis. Furthermore, they concluded that both sensitivity and specificity are excellent for a cowside test and higher than those in two commonly used chemical dipsticks.

In summary, diseases such as metritis, displacement of the abomasum, and ketosis can be evaluated by monitoring rectal temperature, attitude, milk production, and ketone levels in blood, milk, or urine early postpartum. Monitoring health early postpartum assures that all cows are examined during the time when they are most susceptible to disease, allowing the opportunity for early identification of cows that are sick. Employing a postpartum health monitoring program, Benzaquen et al. (2007) reported that early treatment of cows with metritis resulted in pregnancy rates comparable to those of cows without metritis, suggesting that identification of cows with metritis and early and prompt treatment may ameliorate the effects of metritis on reproduction. The following are key points to consider in the application of a postpartum health monitoring program:

- Identify key farm employees who have the interest to work with and treat sick cows. Train them on a periodic basis and work with them side by side routinely. The basic premise in looking for a sick cow is that the cow should be evaluated as a whole, considering attitude, rectal temperature, milk production, and evaluation for ketone bodies.
- Create Standard Operation Practices (SOPs) for detecting sick cows, physical examination, and treatment procedures for individual diseases. Review these practices frequently.
- Based on farm facilities and employee abilities, the veterinarian and producer should decide which program works best for the farm.
- It is important that health monitoring takes place for at least the first 2 weeks postpartum, and that days 3–7 appear to be the most critical.
  - Evaluate attitude, rectal temperature, and blood, milk, or urine sample for presence of ketone bodies daily for 10 days postpartum.
  - Examine cows for metritis, displaced abomasums, and mastitis, if they have a rectal temperature ≥39.4°C or appear sick. Do not rely only on temperature.
  - Cows with ketosis should be treated.
  - Consider an evaluation of uterine discharge on days 4, 7, and 12 to make sure that cows with metritis without fever are not missed.
  - Evaluation of changes in daily milk production for the first 20 days postpartum is a valuable tool that can be used effectively to evaluate health.
  - Look for sick cows beyond the postpartum period. It is important to recognize that sick cow monitoring must be performed in all cows in lactation. Farm personnel involved in moving, feeding, milking, or breeding cows should be cognizant of the fact that they play a major role in the identification of sick cows. Consequently, they too should be trained in how to look for sick cows. Milkers should also be

well trained in how to identify cows with mastitis, as it is an important component in good milking procedures.

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5

Nutritional Management of Lactating Dairy Cows

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Abstract

Nutritional management of lactating dairy cows varies with type of production system, but an effective feeding system allows cows to achieve maximum intake of a properly balanced ration to optimize production, health, and reproduction. Specific feeding strategies are used by the different production systems, and diet formulation and feed delivery will be completely different for cows subjected to a grazing system compared with herds in total confinement. As production per cow continues to increase with genetic selection and improvements in management, the need to provide the correct amount of nutrients and certain dietary compounds such as forage and fiber become more critical, particularly during late gestation and early lactation. Dairy cows in early lactation undergo a period of negative nutrient balance, which can be exacerbated by diseases or external factors that impair feed intake. Formulating diets that maximize nutrient intake in the first weeks postpartum not only improves yields of milk and milk components, but also minimizes losses of body reserves and reduces the risk of postparturient health problems. This is critical because a large component of the success of a nutritional program of a dairy herd relies on feeding cows to minimize health problems. Similarly, as production declines with advancing lactation, so do the nutrient needs of the cow; therefore, tailoring the diet according to feed intake, level of production, and stage of lactation becomes critical to optimize nutrient utilization, reduce feed costs, and minimize the impact of production on the environment.

Introduction

Providing nutrition for dairy cows has evolved from simple systems with grazing and minor supplementation to feeding totally mixed rations (TMR) to meet the nutrient needs for high levels of milk production when taking into account the dynamics of digestion of nutrients. Dairy nutrition is the aspect of any dairy farm that has the greatest impact on the economic success of the enterprise. Dietary ingredients and diet mixing for lactating dairy cows typically account for 45%–50% of the income of a dairy farm. When dry cows and growing heifers are considered, then nutrition can account for up to 60%–70% of the income of a dairy farm. It is not uncommon for feed costs to account for more than 60% of the operating expenses of a dairy farm in the United States.

Feeding Systems and Grouping Strategies for Lactating Cows

Distinct methods of delivering feed to cattle are available, but it is a consensus that for high-producing cows in confinement systems, the delivery of diets as TMR is advantageous to secure adequate intake of all ingredients of the diet and minimize the risk of digestive disorders.

In some production systems, the use of a component-fed system in which cows receive forage separately from the concentrates is common. This is one of the simplest methods to feed cows, as component-fed systems do not require mixing wagons that are needed to prepare TMR. It also allows for individually feeding the concentrate

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Figure 5.1. Cows receiving concentrate feeds after milking in the parlor in a dairy farm in Florida. Excessive intake of highly fermentable feeds can result in digestive disturbances such as rumen acidosis and bloat, and cause milk fat depression.

portion of the diet according to level of production of the cow. Therefore, cows of different production levels and nutrient needs can be grouped together, but fed grain during or immediately after milking according to their nutritional needs. Although this system poses some advantages, it also has several disadvantages: the lack of control of forage intake, risk of excessive concentrate intake, inadequate intake of forage fiber to maintain proper rumen health leading to digestive disturbances, and increased risk of milk fat depression caused by drastic changes in rumen microflora and pH. It is known that intake of large quantities of starchy feeds or feeds that are highly digestible in the rumen can suppress dry matter intake (DMI) (Allen et al., 2009) and influence the digestibility of fiber (Fig. 5.1).

When cows are fed in electronic feeders, concentrates can be dispensed at small quantities throughout the day, which minimizes the need to offer large quantities of high-starch grains for cows to consume in a short period. Each cow carries an electronic device either in a collar, as a pedometer, or as an ear tag/button that allows for entrance in the automatic feeder, which will dispense the desired amount of concentrates. Work in the late 1970s (Frobish et al., 1978) compared feeding 24 cows in two groups, one group individually fed their daily allowance of concentrate during milking, one group in computerized feeders to allow cows to consume the concentrate throughout the day. Cows were fed the forage portion of the diet as corn silage in the feed bunk. Milk production increased approximately 0.7 kg/day with automatic feeders, while forage and concentrate intake remained the same for both groups. Nonetheless, cows were producing only 19 kg of milk/day in the study.

Recent attention has been given to computerized feeding systems to either improve nutrient utilization by tailoring the diet to the needs of the cow or to allow robotic milking systems to work properly by attracting cows to the milking stall. In robotic milking systems, cows must be attracted to the robot to be milked two to three times daily, and this is possible only by offering concentrates during milking. However, when cows are milked more frequently in those systems, the intake of concentrates also increases, which can create a problem if these are rich in starch. A method to minimize the risk of digestive disturbance or milk fat depression is to offer nonforage fiber sources that are high in highly digestible neutral detergent fiber (NDF), but low in starch content in a pelletized form such as citrus pulp, beet pulp, soybean hulls, or corn gluten feed. Studies with high-producing cows in Israel have demonstrated that offering a portion of the concentrate in automatic feeders as nonforage fiber sources in place of starch sources can either maintain or even increase yields of milk and milk components. When conventional starchy pellets were replaced with pellets high in digestible NDF by substituting soybean hulls for ground corn and wheat bran, yields of milk, milk fat, and protein increased in cows producing approximately 40 kg/day (Halachmi et al., 2009), but not in a second experiment with cows producing approximately 35 kg/day (Halachmi et al., 2006). When milk yield was increased, approximately 2 kg/day, in cows fed nonforage fiber sources in place of starchy sources in the component-fed group with computerized feeders, the increment was not accompanied by changes in milk fat and protein contents. Therefore, in component-fed systems, it is advised to provide cows with concentrates

that are somewhat high in NDF and limited in starch. Although in such systems NDF intake may be higher and starch intake lower than desired when considering the total diet (forage and concentrate), this strategy minimizes the risk of depression in DMI and milk fat content, at the same time that it can improve yields of milk and milk components.

Although component-fed systems have been popular in small herds or in herds that cannot handle complete rations, TMR or complete rations have become very popular regardless of herd size because of potential advantages. Complete rations are defined as rations in which the forage and concentrate components are blended and offered together and formulated to a specific nutrient concentration and offered ad libitum to cows. When cows are fed a diet as TMR, they are expected to consume a set amount of forage relative to concentrates; it allows for feeding more than one forage and to secure a more homogenous intake of the different forages offered. Because forage fiber intake is more precisely known, the use of TMR is expected to minimize the risk of digestive disorders and milk fat depression, although neither of the two is completely abolished. It allows for inclusion of dietary ingredients that are less palatable (some acidogenic salts used to prevent hypocalcemia prepartum) or those that can pose a risk to cow health if not mixed properly, such as nonprotein nitrogen sources, trace minerals, and ionophores. It can also potentially improve feed efficiency as it minimizes the risk of drastic fluctuations in rumen pH, osmolarity, and microbial flora. Finally, because of mechanization, it allows for feeding of large groups of cows, which potentially minimizes the labor involved. Despite its advantages, feeding TMR is an excellent method to propagate problems of nutritional origin when diets are not properly formulated or mixed and delivered. For instance, there have been several descriptions in the literature of outbreaks of nutritional problems such as toxicities and botulism that can be propagated in many cows in the herd because TMR facilitates the dispersion of the toxin (Galey et al., 2000; Urdaz et al., 2003).

Feeding TMR allows cows to consume a complete diet that is tailored to the nutrient needs of the specific group of cows, and this will require proper grouping of cows. In many situations, producers opt for a single diet for all lactating cows, and this can be justifiable when production is very high because in such herds even the cows with advanced lactation still maintain high milk production. The assumption in this case is that DMI will vary according to the level of production to accommodate the differences in nutrient needs, and the diet is formulated to not hinder production of the higher-producing cows. In practical terms, the diet is typically formulated to provide sufficient NDF to maintain rumen health and avoid acidosis, at the same time that intake of calories, metabolizable protein (MP), minerals, and vitamins is compatible with yields of milk and milk components of the more productive cows in the group. Many nutritionists will formulate a diet allowing production 20% above the average of the group assuming a certain intake of dry matter (DM). Another strategy is to formulate rations to meet nutrient requirements of the top third of the cows in each group (Fig. 5.2).

Figure 5.2. Cows receiving a diet as TMR in a dairy farm in California. Feeding TMR allows for feeding of large groups of cows a diet that is expected to meet the nutrient needs for high levels of milk production at the same time that it minimizes the risk of digestive disturbances.

In certain cases, cows are grouped based not on factors that are associated with the nutrient requirements, but on management preferences such as reproductive status, which makes difficult to formulate diets based on specific caloric and protein densities. It is not uncommon for producers to note a decline in production when cows are moved to a new group, which also results in concurrent diet change. In fact, regrouping cows typically alters behavior, and cows often require 2–4 days to adapt to the new hierarchy and social status within the new group. When the group change is associated with a diet of lower caloric and nutrient density, then it can cause substantial decreases in nutrient intake and milk production. Moseley et al. (1976) created several dietary scenarios for cows fed TMR by altering the forage-to-concentrate ratios of the diet. When early lactation cows were switched from one group to another and the diet changed from a 40:60 ratio of forage to concentrate to a 60:40 ratio, it caused an abrupt decline in DMI and milk production that was not recovered even 3 weeks later.

A common system for grouping cows based on behavior, social aspects, and nutrient needs is to segregate primiparous from multiparous cows whenever possible. Although the nutrient needs of primiparous cows are not necessarily different from those of multiparous cows with similar production, segregating cows based on parity typically improve performance of primiparous cows because of the differences in social behavior and the problems of negative interactions with cows of a higher social ranking. Cows should also be grouped according to their health needs, as those in the first 3–4 weeks postpartum require additional care. Furthermore, cows in the first weeks postpartum might benefit more from certain dietary additives and supplements that are targeted to minimize health issues that occur more commonly in this stage of lactation. Because of extensive lipid mobilization in the first 3 weeks postpartum, early lactation cows tend to experience greater declines in DMI when fed diets containing excessive amounts of highly fermentable carbohydrates (Allen et al., 2009). It is thought that increased fatty acid oxidation in the liver through ketogenesis exacerbates the hypophagic effects of propionate when cows are fed diets high in rumen-degradable starch. Furthermore, in early lactation, grouping cows separately allows producers to provide diets higher in forage NDF, which is beneficial to rumen fill and minimizes the risk of subacute rumen acidosis and displacement of abomasum. Finally, cows in early lactation have substantial secretion of protein in milk because protein content in colostrum and milk in the first days postpartum is two- to fivefold greater than that of milk after the first week of lactation. During this period, DMI is usually inadequate to meet the caloric and amino acid needs for maintenance and milk synthesis. Cows can draw on body fat reserves to meet the caloric needs, but protein reserves are more limited. Feeding diets with additional protein content or with protein sources of lesser ruminal degradability typically enhance yields of milk and milk protein in early lactation, although when additional protein feeding stimulates milk yield in early lactation with no change in DMI, it can also exacerbate body fat losses in cows in negative energy balance (Orskov et al., 1977).

It is recommended that cows remain in the early lactation group for at least 3–4 weeks. This is the period when body weight and condition score losses are more pronounced; it is when cows experience the lowest energy balance and when cows require diets with the highest nutrient density; and it is the period when overfeeding starch might suppress DMI and exacerbate digestive diseases that occur because of initiation of lactation and concurrent dietary changes. Once cows leave the early lactation pen at approximately 3–4 weeks postpartum, two grouping and feeding strategies are typically used. The first is to allocate cows to a group where they remain until the date when they will be dried off. Minimizing pen movements is now seen as beneficial to production because it reduces turmoil in groups of cows, which typically occurs in herds with continuous cow movement. The concept is that in a short period of time, a pen can be filled with a group of cows, and no additional movement of animals occurs for several months. Obviously, this can be done only in large herds with several groups. Cows in those systems would be fed the same diet as TMR until the dry-off date. Another system is to move cows from the so-called high-group to a low-group when production has declined below a certain threshold. In the latter scenario, the concept is that these lower producing cows do not require a diet with the same nutrient density as high-producing cows, and the excess of nutrient intake can potentially result in cows that become overconditioned, which may be more costly. Working with several diets for the lactating cows is more appropriate for herds with low production, typically below 10,000 kg/year as a large proportion of the cows with advanced gestation will have production that does not require diets with high nutrient density. On the other hand, in high-producing herds with average production per cow above 12,000 kg/year, it is not uncommon for groups of late lactation cows to still be producing more than 35 kg/day, and these cows might either suffer production losses or not recover body condition if fed diets of lower nutrient density. This might be particularly critical when high-producing herds are able to maintain good reproductive performance and, consequently, lac-

tations are shorter than 11 months. In those situations, diets that restrict nutrient intake limit the ability of cows to replenish body reserves, which can influence production and reproduction in the subsequent lactation.

One of the implications of feeding a single group TMR is not only the potential to overfeed calories that result in excessive weight gain, but particularly protein and some minerals which might have important consequences for the environment. Early lactation cows and cows with high production are typically fed diets containing 16.5%–18% crude protein (CP), but as lactation progresses and production declines, there is little evidence that feeding diets with more than 16% CP influences yields of milk or milk protein. Therefore, when lactating cows are grouped according to production and fed diets to meet the needs for lactation and replenishment of body reserves, there is an opportunity to minimize the losses of nitrogen to the environment. Table 5.1 depicts potential benefits and concerns of using a single lactating diet contrasting with multiple diets for the lactating herd.

When feeding TMR, special attention is needed for the presentation of the diet. Typically, diets fed as TMR contain 45%–60% DM because silages, high-moisture grains, and wet by-product feeds are common ingredients of dairy cow rations. Feeding diets with DM content less than 45% might suppress intake because these diets typically contain silages with excessive concentrations of organic acids that might have not fermented properly, or just because of overall moisture of the ration, which would require the cow to spend more time feeding to compensate for the greater water content. Furthermore, in some climates, the high water content in some TMR can make them less stable in the feed bunk, particularly during the summer months, which can result in spoilage and suppression in intake. In addition to moisture content, the particle size of the forages and some by-products should be evaluated to avoid either excessive concentration of very long particles, which would favor sorting against these particles, or inadequate content of long particles, which typically reduces the physical effectiveness of the NDF, thereby reducing fiber digestibility and increasing the risk of digestive problems and milk fat depression. A good rule of thumb is to maintain forage particles of a length smaller than the muzzle of the cow. This prevents the cow from sorting against these particles, which likely provide the bulk of the physically effective NDF. Additionally, rations should contain

Table 5.1. Some advantages and disadvantages of feeding lactating cows single or multiple diets during the lactation

	Number of TMR fed to lactating cows	
	Single	Multiple
Convenience and risk of errors	Feeding a one-group TMR to the entire lactating herd simplifies the nutritional program of the lactating herd and minimizes the risk of errors in diet mixing and delivery.	Feeding multiple diets with different ingredients requires additional labor for mixing of different grain mixes and delivery of different diets. It increases the risk of errors during preparation of diets if different ingredients are used in the distinct lactation diets. It also increases the risk of errors during delivery.
Body condition score	It can be advantageous in high-producing herds in which recovery of body reserves is critical for future lactation.	It can minimize overconditioned cows in herds with low milk production or with reproductive problems causing extended lactation.
Production	It usually favors higher production and minimizes the production losses with movement of cows from one group to another.	It can cause milk production to drop when cows are moved to a group in which the diet differs, particularly if forage quality decreases, fiber increases, and protein content and quality decreases in the new diet.
Cost of feeding cows	It is usually more expensive, as the diet for single-group TMR is usually formulated to meet the needs of the highest producing cows in the herd.	It is usually cheaper, as the veterinarian or nutritionist can formulate diets with less expensive ingredients to the low-producing cows and offer specific protein supplements and feed additives to groups of cows that are more likely to benefit because of higher production.
Efficiency of nutrient utilization	It tends to decrease the efficiency of nutrient conversion into milk and to increase the fecal and urinary excretion of nutrients into the environment.	It tends to increase the efficiency of nutrient conversion into milk when the dietary changes are not followed by production losses. Nutrient excretion into the environment is minimized.

sufficient concentration of long particles to stimulate cud chewing and rumination.

A method to determine particle size of forages and diets is by using the Penn State Particle Separator. Using the separator, it is possible to determine the particle size distribution of TMR according to three different screen apertures and the bottom pan. The Particle Size Separator segregates feed particles into those with lengths >19 mm, between 8 and 19 mm, between 1.18 and 8 mm, and <1.18 mm. It has been suggested that 1.18 mm is the critical length governing retention of feed particles in the reticulo-rumen (Mertens, 1997), thus measurement of particle length >1.18 mm may be useful in evaluating mixing of diets presented to cows to maintain proper physical effectiveness of fiber. It is suggested that the Penn State Particle Separator be shaken at a frequency of 66 cycles/min with a stroke length of 17 cm. Samples of forage and TMR are sieved, and then physical effectiveness of NDF is calculated after correcting for DM and the NDF content.

Table 5.2 depicts examples of a single TMR composed of corn silage, alfalfa hay, whole cottonseed, brewer's grains, ground corn, and soybean meal that was fed individually to 37 cows and evaluated daily during a 4-day period for its particle size distribution and concentration of DM and NDF in the different sieves to calculate the physically effective NDF. The diet contained an average of 32.4% ± 2.5% NDF and 22.1% ± 4.1% acid detergent fiber (ADF), and the amount refused by each cow contained on average 31.6% ± 3.5% NDF and 21.9 ± 3.4% ADF. In this example, sorting and NDF distribution in the different sieves and the calculated physically effective NDF were very similar between what was offered and refused by these cows. This indicates that diet mixing and sorting was not an issue.

It is important that the physical effectiveness should be determined on fresh samples, and then expressed as a proportion of the total DM sieved. This requires DM analysis for the original sample and the material retained on each sieve. The correction for DM is important because moisture content of the sample affects its physical effectiveness, and it can result in overestimation of up to 30% when uncorrected for DM content (Kononoff et al., 2003).

DMI

Intake of DM is the single most important determining factor that influences milk yield and susceptibility to diseases of the intermediary metabolism in early lactation. The shift from a nonlactating, gestating status to a lactating and nonpregnant status as observed in the first weeks postpartum is marked by a period of nonoptimal DMI in dairy cows. This inadequate intake of DM often results in the occurrence of metabolic disorders such as fatty liver, ketosis, and displacement of abomasum.

Determining DMI is a key component in diet formulation as cows require quantities of specific nutrients for optimal production and health. Feed intake is influenced by many interacting factors, some of a dietary nature, but many of animal or environmental origin. In early lactation, diseases and fever that occur after calving typically suppress intake. Furthermore, mobilization of adipose tissue in late gestation and early lactation and subsequent increased concentrations of nonesterified fatty acids (NEFA) and beta-hydroxy butyrate (BHBA) are usually associated with a drop in intake (Grummer et al., 2004). The amount of DM consumed by dairy cows per day is a function of meal size and intermeal interval, which are typically controlled by physical and

Table 5.2. Particle size distribution of a TMR individually fed to lactating dairy cows and calculated physically effective NDF (NDF_{PE}) using >1.18 mm as cutoff

	Particle size, mm				
	>19	8–19	1.18–8	<1.18	NDF_{PE}
Offered retained, %					
As is	5.0 ± 1.3	37.7 ± 3.9	44.9 ± 2.1	12.9 ± 2.3	
DM	5.2 ± 1.5	34.4 ± 3.6	44.8 ± 2.4	15.7 ±3.0	
NDF as DM	1.7 ± 0.6	11.1 ± 1.6	14.5 ± 1.2	5.1 ± 1.1	27.3 ± 2.4
Refused retained, %					
As is	4.2 ± 1.9	36.3 ± 5.2	48.4 ± 4.4	11.1 ± 3.6	
DM	4.2 ± 2.0	36.1 ± 5.3	46.3 ± 4.4	13.4 ± 4.3	
NDF as DM	1.4 ± 0.7	11.4 ± 2.3	14.6 ± 2.0	4.2 ± 1.4	27.4 ± 3.4

neurochemical stimuli originating in the digestive tract (Forbes, 2005).

The ability of cows to consume feed is determined by many interacting factors, and predicting feed intake is a critical component of formulating diets for lactating dairy cows. Despite the challenges in predicting feed intake, it is imperative that nutritional consultants formulate diets based on the amount of nutrients consumed by the cow and not necessarily the concentration of nutrient in the ration. Although diets are typically formulated based on their caloric content, precisely their net energy for lactation (NE_L) concentration, CP concentration, and mineral and vitamin concentrations, the reality is that cows require specific amounts of nutrients and calories to perform satisfactorily.

Allen et al. (2009) integrated ideas based on the concept that increased oxidative activity in the hepatic tissue signals centers in the brain to influence satiety and hunger. Eating is controlled by the integration of peripheral signals in brain feeding centers. He suggested that dairy cow diets must contain a minimal concentration of relatively low-energy roughages for proper rumen function because signals from ruminal distension can suppress feed intake because of rumen fill, particularly when the drive to eat is high such as in high-producing cows between 2 and 5 months postpartum. On the other hand, signals originated from metabolism of the digestive tract such as the intestine and liver predominate in controlling appetite when distension of the rumen-reticulum is limited. This is the case of diets low in forage and NDF in which metabolites flowing to the small intestine and oxidative pathways in the liver signal the central nervous system to suppress appetite by reducing hunger or reaching satiety prematurely. Therefore, it is expected that feed intake of cows will vary according to their level of production and physiological state and that dietary influences on intake will have different effects at different stages of lactation.

Meeting the Caloric Needs of Lactation

Energy is typically measured in calories, and the caloric content of different components of the diet differs. For carbohydrates it is 4.2 Mcal/kg, fat is 9.4 Mcal/kg, protein is 5.6 Mcal/kg, and ash is 0 Mcal/kg. These are values based on burning these components in a bomb calorimeter to measure their gross energy content. However, the energy available to be used by the animal for maintenance of cellular activities, growth, weight gain, and synthesis of milk is not the gross energy of the feedstuffs consumed. When feeds are consumed, a portion of them is not digested, and the undigested material appearing in feces results in fecal losses of calories. Additionally, during the process of digestion, some calories from the feed is not available to be transferred to the animal because part is lost in the form of digestive gases such as methane produced in the rumen-reticulum and in the large intestine. After the end products of digestion are absorbed, some of the calories contained in these substrates are also lost in the urine. Finally, there is a caloric cost for the process of digestion and absorption of nutrients, which needs to be compensated with calories provided by the dietary nutrients. Therefore, from the initial gross energy concentration of feedstuffs provided in the diet of a cow, a substantial proportion is not available for productive processes such as milk synthesis, thereby reducing the estimated energy density of the ingredient.

The factorial system of energy flow is depicted in Figure 5.3. It includes the shifts from gross energy to digestible energy to metabolizable energy and, finally, to net energy.

Although the caloric density of a diet is a function of its composition and the ability of the cow to digest and absorb its nutrients, it is known that for ruminant rations, energy density is not static but a dynamic value, as it can increase or decrease according to level of intake and retention time in the rumen. Typically, as intake increases, which results in shorter rumen retention times, digestibility of feed declines. As digestibility in the rumen declines, there is a compensatory effect of the small and large intestines to digest a larger portion of the total DM consumed. This influences the type of substrates available for absorption by the gut of the cow. For instance, as digestion of carbohydrates shifts from the rumen to the intestines, overall digestibility declines, and the end products change from volatile fatty acids (VFAs) to more glucose and lactate. Also, as digestion of carbohydrates shifts from the rumen to the intestines, less microbial protein is produced, and more nitrogen is lost in the feces. This influences the provision of calories and amino acids to the lactating cow.

Using this concept, it is clear, then, that a cow that consumes more DM, for instance 28 kg/day, is eating a diet with calculated energy density that is inferior to that of a cow consuming the same diet, but only 18 kg/day. Table 5.3 depicts the change in energy density of a low and a high forage diet fed to a group of cows with different DMI using the NRC (2001) software. Because of the energy discount for losses in digestibility, the NE_L content of the low forage diet is 1.57 Mcal/kg for the cows consuming 28 kg/day of DM. On the other hand, the same diet fed to a cow consuming only 18 kg/day results in dietary NE_L content of 1.74 Mcal/kg. Now, in the case of the high forage diet, the change in energy density is of lesser magnitude, from 1.55 to 1.65 Mcal/kg with the

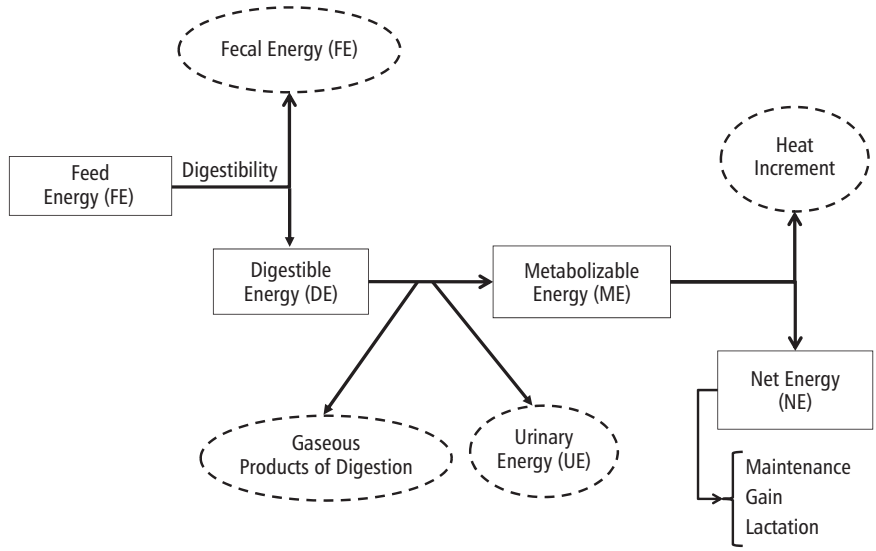

Figure 5.3. Factorial system of energy flow. Dietary ingredients contain a certain amount of gross energy. During the process of digestion, this caloric density declines because of losses of calories during digestibility, production of gases in the rumen-reticulum, loss of energy in urine, and the energy cost of digesting and absorbing nutrients. When dietary energy concentration is expressed, the value is typically given in Mcal/kg of net energy.

Table 5.3. Effect of intake on energy density and protein content of diets fed to cows with different levels of DMI

	Diet	
	Low forage	High forage
Corn silage	20.0	25.0
Alfalfa silage	11.0	10.0
Bermudagrass silage	9.0	20.0
Ground corn	28.7	18.6
Citrus pulp	15.0	10.0
Calcium salts of palm fatty acids	1.8	1.8
Soybean meal	10.0	10.0
Blood and fish meals	2.8	2.8
Minerals and vitamins	1.8	1.8
Nutrient content		
Crude protein, %	16.6	16.6
Fat, %	4.8	4.6
Nonfibrous carbohydrates, %	45.7	38.0
Neutral detergent fiber, %	27.0	34.7

	DMI group			
	High	Low	High	Low
DMI, kg/day	28.0	18.0	28.0	18.0
NE_L, Mcal/kg	1.57	1.74	1.55	1.65
Rumen degradable protein, %	9.8	10.4	9.8	10.4
Microbial protein/metabolizable protein	54.3	58.9	54.6	58.5

change in DM from 28 to 18 kg/day. This indicates that the NE_L of a diet is more severely penalized for increases in DMI when the ration is composed by carbohydrates of greater digestibility such as sugars, starch, and soluble fiber, as opposed to NDF.

In early lactation, most cows are unable to meet their caloric needs because DMI lags behind the increase in milk production. Furthermore, the body weight loss experienced by the cow in early lactation results is high concentrations of NEFA in plasma, which are extensively transferred to milk fat. This increases the milk fat concentration to values greater than 4.5% in most cows in the first 2–3 weeks postpartum, thereby further increasing the energy drain caused by lactation.

Energy balance is the difference between caloric consumption and energy needs of the cows. The caloric consumption is the result of DMI times the energy density of the diet. The energy needs by a dairy cow are the summation of the requirements for maintenance, milk synthesis, tissue deposition in the pregnant uterus, and tissue deposition because of growth or weight gain. Therefore, the calculation of energy balance can be as follows:

$$\text{Energy balance, Mcal/day} = [\text{DMI (kg/day)} \times \text{NE}_L\text{ (Mcal/kg)}] - [\text{Energy for maintenance (Mcal/day)} + \text{Energy for milk (Mcal/day)} + \text{Energy for the gravid uterus (Mcal/day)}].$$

If cows are in positive energy balance, then there will be a surplus of calories that can be used for body weight gain. On the other hand, if cows are in negative energy balance, then there will be lack of calories, and cows will have to lose body weight to maintain the same level of milk production. The energy needs for maintenance are calculated as follows (NRC, 2001):

$$\text{Energy for maintenance, Mcal/day} = 0.08 \times \text{BW}^{0.75}.$$

Therefore, for a cow weighing 650 kg, her metabolic weight, which is the BW to the power of 0.75, would be 128.7 kg. The NE_L needed for maintenance of this cow would be 0.08 × 128.7, which is 10.3 Mcal/day.

The NE_L content of milk varies with its concentrations of fat, protein, and lactose. It can be calculated using one of the following two formulas:

$$\text{NE}_L\text{, Mcal/kg} = [(0.0929 \times \text{Fat\%}) + (0.0563 \times \text{Protein\%}) + (0.0395 \times \text{Lactose\%})];$$

or

$$\text{NE}_L\text{, Mcal/kg} = [(0.0929 \times \text{Fat\%}) + (0.0563 \times \text{Protein\%}) + 0.192] \text{ (NRC, 2001).}$$

Table 5.4 depicts the energy concentration of milk from Holstein and Jersey cows that vary in their fat and true protein contents. It is clear from the formulas and from the results of the table that the fat content represents 40%–50% of the total energy concentration of milk. Lactose typically is not variable in milk, and most cows maintain a concentration of 4.7%–4.9% lactose. True protein can vary, but the magnitude is much less than that observed for milk fat.

Using the values described in the table, one can calculate the energy needs of the average dairy cow of a group using the body weight, the milk yield, and the composition of the milk. For instance, if a diet is formulated to meet the needs of a lactating Holstein cow weighing 650 kg and producing 40 kg of milk with 3.80% fat and 3.30% true protein, then this cow needs to consume

$$0.08 \times (650)^{0.75} = 10.3 \text{ Mcal/day for maintenance}$$

$$40 \times 0.728 = 29.12 \text{ Mcal/day for milk synthesis.}$$

Table 5.4. Composition and energy density of milk of high and low component Holstein and Jersey cows

	Holstein		Jersey	
Milk, %	Low component	High component	Low component	High component
Fat	3.20	3.80	3.90	4.80
Protein	3.00	3.30	3.30	3.75
Lactose	4.80	4.80	4.80	4.80
Mcal/kg				
Fat	0.297	0.353	0.362	0.446
Protein	0.169	0.186	0.186	0.211
Lactose	0.189	0.189	0.189	0.189
Milk, Mcal/kg	0.656	0.728	0.738	0.847

Assuming that there is no change in body reserves (no gain and no loss of body weight), then the daily energy intake should be at least 39.32 Mcal of NE_L. Considering now the DMI of this group of cows, the caloric density of the ration per kilogram can now be determined. If intake is 24 kg/day, then the ration should have an NE_L concentration of

$$39.32 \text{ Mcal}/24 \text{ kg} = 1.64 \text{ Mcal/kg}.$$

Any additional calorie consumed is expected to be diverted either into additional milk or into body reserves. In general, most lactation diets contain an estimated NE_L that ranges from 1.60 to 1.75 Mcal/kg. Diets with energy density less than 1.60 Mcal/kg have too much forage, an excessive concentration of NDF, forages sources containing high NDF and lignin, or ingredients of low rumen digestibility. Obviously, based on the discounts for DMI and rate of passage, when the energy density is calculated using cows with very high intake, even a diet with a large proportion of concentrates can have a low calculated NE_L (Table 5.3). In contrast, very seldom do lactation diets surpass 1.75 Mcal/kg because such diets would not provide sufficient forage fiber to maintain rumen health. Also, they would have to contain large quantities of supplemental fat, which when fed in excess can be detrimental to DMI and fiber digestion, thereby suppressing cow performance.

Fiber Carbohydrates

One of the first steps in diet formulation is to make sure that the ration provides a minimum amount of NDF to keep rumen health and to avoid digestive disturbance and milk fat depression. NDF, particularly of forage origin, is required to stimulate cud chewing and rumination, which enhance secretion of salivary buffers to counteract the effects of acid production in the rumen. Fiber is also needed to stimulate rumen motility, which is critical for the ability of VFA produced during bacterial digestion in the rumen-reticulum to be absorbed. As the rumen contracts, the VFA present in the rumen fluid come in contact with the epithelium, and absorption takes place.

Lactating cows do not have a set requirement for fiber in their diets, but rations that are limiting in fiber content predispose cows to digestive disturbances such as rumen acidosis and diarrhea, increase the risk of displacement of abomasum, result in milk fat depression, and limit energy intake and microbial protein synthesis. Therefore, it is critical that a minimum amount of dietary fiber, preferably of forage origin, be fed in the ration of dairy cows. As the forage-to-concentrate ratio in the diet increases, so does eating and ruminating times, chewing time, and salivary production. Nevertheless, when dietary forage and NDF are excessive, rumen fill can then limit DMI and productivity.

Forage fiber is critical to the buffering of the rumen. It is estimated that 5 Eq of VFA are produced for each kilogram of DM consumed by dairy cows (Gäbel and Aschenbach, 2006). Allen (2000) estimated that VFA production in the rumen is approximately 7.5 Eq/kg of organic matter fermented in the rumen. In addition, Na^+ in the ruminal fluid is exchanged with H^+ present in the cytoplasm of the rumen epithelial cells, and for each mol of VFA absorbed, an equivalent 0.5 mol of Na^+/H^+ exchange occurs. Therefore, in addition to the acid load from VFA production, absorption of Na^+ results in additional H^+ returning to the rumen fluid that needs to be buffered. Consider a lactating cow consuming 25 kg of DM, of which 50% is ruminally fermentable organic matter. This diet can potentially generate 93–125 Eq of organic acids as VFA in the rumen of the cow. An additional 20%–40% more H^+ can enter the rumen as sodium absorption occurs. Therefore, the total acid load can be as much as 140–150 Eq/day.

Salivary flow in dairy cows ranges from 230 to 290 L/day, and saliva contains 26 mEq of HPO_4^{-2} and 126 mEq of HCO_3^-, which totals 152 mEq of buffer/L of saliva. Considering these values, the amount of acid that can be buffered by saliva is approximately 44 Eq/day, which represents only 30% of the estimated acid load in a high-producing cow consuming large quantities of ruminally fermentable organic matter. The remainder of the acid load has to be either buffered by other dietary anions such as bicarbonate from the diet, absorbed through the rumen epithelium, or removed from the rumen with transit of the liquid phase. In fact, the capacity of the rumen epithelium to absorb VFA determines the intraruminal pH and the risk of subacute rumen acidosis (Penner et al., 2009). The mean ruminal pH increases linearly as the absorptive capacity of the epithelium increases (Penner et al., 2009). These results suggest that cows that are more capable of absorbing VFA are expected to have a reduced risk of subacute rumen acidosis. Furthermore, because fiber stimulates rumen contractions needed to move VFA close to the epithelium, it is then pivotal to formulate diets with adequate forage and physically effective fiber to stimulate VFA absorption and reduce their accumulation in the rumen fluid.

Most diets of lactating dairy cows should contain between 28% and 35% of the DM as NDF, and 60%–70% of this NDF should be of forage origin. Furthermore, the particle size of the forage and high fibrous by-product should be long enough to stimulate cud chewing and rumination. It has been suggested that a minimum of 1.2 mm in length is needed for particles to be retained in

the rumen and stimulate contractions and rumination (Mertens, 1997). However, even when NDF particles are small, they also cause a dilution effect if replacing starch or other readily digestible carbohydrates in the diet. Therefore, dietary fiber not only stimulates buffering of the rumen and counteracts the acid load, but it also dilutes the more digestible dietary carbohydrates, thereby minimizing the total acid production. Furthermore, digestion of NDF and other fiber materials does not support lactic acid-producing bacteria. It is known that lactic acid is 10 times stronger than VFA because its dissociation constant (pK) is lower. For VFA, the pK is 4.8, whereas for lactic acid it is 3.8. This means that at a pH of 4.8, 50% of the VFA is in its protonated form (acid form such as acetic acid, propionic acid, and butyric acid) and 50% in its dissociated form (acetate, propionate, and butyrate). On the other hand, for lactic acid at a pH of 3.8, 50% will be in the acid form (lactic acid) and 50% in its dissociated form (lactate). Therefore, lactic acid has a greater capacity to release protons at lower pH, and the proportion of free protons will be greater at lower pH when the solution contains lactic acid as opposed to VFA.

Not all fiber sources are the same, and some forages are more effective in stimulating cud chewing and rumination than others. Similarly, not all high-fibrous byproducts provide the same physical effectiveness from their fiber. Retention of particles in the rumen is critical for fiber to stimulate cud chewing and rumination, and several factors influence mean retention time (Mertens, 1997; Huhtanen et al., 2006):

1. Type of forage, which is related to the plant anatomy: Tropical grasses are retained longer than legumes because of their plant structure, and stems are retained longer than leaves.
2. Fiber content: Diets that provide more fiber form a fibrous mat that facilitates retention of particles in the middle and dorsal portions of the rumen-reticulum.
3. Particle size: Larger particles are retained longer than smaller particles because they need to be chewed and to lose entrapped air to sink in the rumen floor close to the rumen-omasal orifice.
4. Critical particle sizes are: <0.2 mm = no chewing activity and immediate passage; 0.2–1.2 mm = fast passage through the rumen-reticulum; >1.2 mm = requires chewing and are retained in the rumen longer.
5. Density: Particles that are denser tend to have a shorter retention time. For instance, cottonseed hulls are very high in NDF, and despite the smaller particle size than many forages, their low density forces them to be retained in the middle and dorsal portions of the rumen, thereby preventing them from leaving the rumen which stimulates cud chewing and rumination.
6. Degree of hydration and buoyancy: Particles that are drier and have air trapped inside require chewing to disrupt their physical structure so they can become more dense and sink in the rumen fluid close to the omasal orifice.
7. Associative effects with other feeds: The effectiveness of fiber in some feedstuffs can increase in the presence of a rumen mat. In diets that provide fiber with long particles, the formation of a mat in the rumen facilitates the retention of smaller particles such as fibrous by-products, which increase the physical effectiveness of their NDF.

Because of these features, it is common to mix different types of forages in most lactation diets and to include some that have inherently greater ability to be retained in the rumen. For instance, because of particle size and rumen retention time, hays of wheat, oat, and subtropical grasses commonly used in dairy cow rations (Bermudagrass, Tifton 85 Bermudagrass) favor rumination when compared with the same amount of NDF from corn silage. Similarly, the longer particle size and the high lignin content in the NDF of alfalfa hay improve the physical properties of the diet when blended with grain silages, and the blend usually improves rumination time when compared with the silages alone.

Diets of cows in early lactation should have higher forage and fiber contents because of the abrupt dietary changes that come with moving from the late gestation nonlactating state to the early lactation group. These cows are more susceptible to digestive disorders such as diarrhea and displacement of abomasum, and excessive dietary starch tends to suppress intake in early lactation cows more than in cows that are past the first 4 weeks postpartum. Considerations for feeding of fiber and other carbohydrates are provided in Table 5.5.

Nonfibrous Carbohydrates

Most of the calories provided by the diet of dairy cows originates from the digestion of nonfibrous carbohydrates (NFCs) in the rumen and intestines. NFCs are all of those not separated in the NDF analysis and can be also called neutral detergent soluble carbohydrates. They are composed of starches, sugars (glucose, fructose, and sucrose), soluble fiber (pectin, glucans, and galactans), fructans, and organic acids (malic and fumaric). The different fractions of the NFC are not always chemically analyzed because of the lack of standardized laboratory procedures, but NFC are often calculated using the following formulas:

Table 5.5. Considerations for carbohydrate feeding of lactating dairy cows

Carbohydrate fraction	% of diet DM	Manipulation of the fraction
Nonfibrous carbohydrates	35–42	Reduce this fraction when forage NDF and physically effective NDF of the diet are low.
Starch	20–26	Reduce starch in the diet as its rumen degradability increases.
Rumen-degradable starch	16–22	Reduce this fraction when forage NDF and physically effective NDF of the diet are low.
Sugars	5–8	No manipulation
Pectins and glucans	6–14	Use to replace starch in diets that have limiting NDF and forage NDF. It can also be used to replace forages when forage quality is poor or NDF in the diet is high.
NDF	28–35	Increase as the digestibility of the nonfiber carbohydrate and starch fractions increase, or when rumen digestion of NDF increases.
Forage NDF	16–23	Increase as the digestibility of the nonfiber carbohydrate and starch fractions increase, or when rumen digestion of NDF increases.
Physically effective NDF	>20	Increase as the digestibility of the nonfiber carbohydrate and starch fractions increase, or when rumen digestion of NDF increases.
Noncarbohydrate compounds that influence rumen pH		
Buffers such as $NaHCO_3$	0.7–1.0	Allows for reduction of 1 percentage unit of physically effective NDF when fed at 0.7%–1% of the diet DM.
Alkalinizing agents (MgO)	0.2–0.3	No manipulation

$$\text{NFC} = 100 - (\%\,\text{NDF} + \%\,\text{crude protein} + \%\,\text{fat} + \%\,\text{ash})$$

or

$$\text{NFC} = 100 - [(\%\,\text{NDF} - \text{NDF insoluble protein}) + \%\,\text{crude protein} + \%\,\text{fat} + \%\,\text{ash}]$$

The first equation is the most commonly used, but the second, which includes the CP retained in fiber, is more accurate and corrects for protein that otherwise is counted twice, thereby underestimating the true NFC content.

In most lactation diets, the major component of the NFC fraction is starch, and starch is the primary component of dairy cattle diets used to promote increased production. This is why optimal starch utilization is pivotal to improving efficiency of production of lactating dairy cows. Starch is also the most variable component of the NFC relative to ruminal and intestinal digestibility. Sugars ferment very quickly in the rumen, and when they are contained within plant cell walls, they are retained in the rumen a sufficient length of time to be extensively digested; none actually reaches the small intestine. Similar to sugars, soluble fiber is extensively fermented in the rumen, and the rate of digestion is either equal to or greater than that of most starches. On the other hand, the rate of starch fermentation in the rumen varies with type of grain and degree of processing. The major source of dietary starch for lactating cows in most of the world is corn, but in some places, other high-starch grains are also extensively fed to cows. In the United States, corn, oats, barley, and wheat are fed to lactating cows in amounts of 94%, 18%, 14%, and 7%, respectively. Normally, starch degradability in the rumen ranks as the following: oats > wheat ≥ barley > corn > sorghum. This sequence is observed when grains are unprocessed. Nevertheless, when subjected to processing either by dry-rolling, cracking, grinding, reconstituting, early harvest ensiling (high moisture), popping, exploding, roasting, micronizing, or steam-flaking, the grains with the slowest rate and the least digestibility in the rumen tend to benefit the most. Therefore, to improve starch utilization in the rumen, grain sources are extensively processed to increase both the rate and the extent of starch fermentation and ruminal digestibility. Feeding processed grains to dairy cows enhances the supply of calories to the animal because of increased VFA production, particularly propionate, which is gluconeogenic, increases synthesis of microbial protein, and improves nitrogen utilization because of greater recycling to the rumen-reticulum (Theurer et al., 1999).

Starch utilization by dairy cows is markedly enhanced by proper grain processing. Steam-flaking of corn and sorghum grains improves the NE_L concentration of the grains approximately 8%–10% (Theurer et al., 1999).

This response was observed because steam-flaked corn and sorghum have greater ruminal starch digestion, which results in increased synthesis of propionate and microbial protein. The increased supply of gluconeogenic precursor and the improved supply of high-quality amino acids enhance the mammary uptake of substrates for milk synthesis. Shifting the site of starch digestion from the rumen to the small intestine is of little advantage to dairy cattle. The net uptake of glucose by the portal drained viscera is very low or even negative (Theurer et al., 1999; Reynolds, 2002), suggesting that the glucose produced during starch digestion in the small intestine is either used by the viscera or converted and absorbed as lactate.

Corn is typically processed by grinding finely, preserving as high moisture, or by steam-flaking. Fine grinding increases the surface area for microbial attachment, but it is less effective in disrupting the protein matrix in which the starch granules are embedded. On the other hand, high moisture and steam-flaking maximize starch digestion in the rumen and intestine by making starch granules more available for microbial attachment and enzymatic digestion. In the case of barley, the starch is more readily degradable than corn starch because upon cracking the pericarp after mastication or processing, the protein matrix in barley is readily solubilized and penetrated by proteolytic bacteria, whereas the corn protein matrix is more resistant to microbial attachment and digestion. Work in Canada has created the concept of processing index (PI) to describe the degree of processing of the grain. Processing index is the density of the grain after processing expressed as a percentage of its original density before processing. Barley is typically rolled, which reduces the density of the grain. Values for barley generally range from 60% to 80%, and the smaller the value, the more extensively processed the grain is and the more digestible starch will be in the rumen. The optimum processing of corn is by steam-flaking to reduce the grain density to 360 g/L. As for barley, the optimum processing is by steam-rolling to result in a PI of 65%. Although processing of grains benefits dairy cow performance, it is important to have careful consideration of the total amount of dietary starch and ruminally degradable starch as, when excessive, they suppress DMI and predispose cows to subacute rumen acidosis (Allen, 2000), diarrhea, and milk fat depression.

Typical concentrations of NFC in rations for dairy cows usually range from 35% to 42% (Table 5.5). Common recommendations for dietary starch content in diets of dairy cows range from 23% to 30% of the diet DM, although the upper values are used restrictively and result in greater risks of digestive problems. Surveys of dairy herds with rolling herd average production above 12,500 kg of milk per cow per year found that dietary starch content ranged between 15% and 30% (Dann, 2010). Therefore, it is possible to achieve high production per cows with a wide range of starch content in the diet. However, as the dietary starch concentration declines, the need for better quality forages and more digestible sources of NDF increases. If forage quality is limiting, it is unlikely that low starch diets will promote high production. Strategies for using low starch diets include feeding more nonforage fiber sources, such as soybean hulls, citrus pulp, beet pulp, and almond hulls. These byproducts are high in energy and NDF, but with NDF of high ruminal digestibility. This allows for inclusion of less total forage NDF when forage quality is not optimum. It is also possible to replace some of the starch with sugar sources such as molasses, which can be successfully included in up to 7%–8% of the diet DM (1.5–2 kg/day). Higher dietary intakes are not desirable because fermentation of sucrose favors butyrate synthesis, which can affect rumen epithelium health. Also, molasses is usually high in sulfates, and excessive sulfate intake is a risk factor for development of polioencephalomalacia.

Supplementation with Fats

Dietary supplementation with fats has long been recognized as beneficial to lactation performance of dairy cows (Palmquist & Jenkins, 1980). Fat sources are typically added to lactation rations to increase the energy density in an attempt to improve yields of milk and milk components because most fat sources contain 2.7-fold more calories than grains high in starch. More recently, attention has been given to the type of dietary fats used and their fatty acid profile. It is well-known that mammalian cells cannot synthesize fatty acids that have a double bond in the acyl chain beyond the ninth C counting from the carboxyl end; these fatty acids are called essential and have particular effects on cell metabolism, gene expression, and immune response. These differential effects of fatty acids on cellular functions have created renewed interest in increasing the postruminal supply of specific fatty acids to manipulate reproduction and health of dairy cows.

Characterization of Fat Sources

Feedstuffs that contain a high fat content (>18% of DM) are considered important sources of dietary fat. Some are sources of only fat (>80% fatty acids), such as yellow grease, vegetable oils, beef and porcine tallow, poultry fat, prilled hydrogenated fatty acids, and calcium salts of fatty acids. Others are called commodity fats, as they provide not only fat, but also other nutrients such as

protein and NDF. Examples of the latter are whole and processed oilseeds such as cottonseed, soybeans, canola, flax, and sunflower.

Fat sources are characterized based on their origin (animal and vegetable), concentration of total fatty acids and other nutrients, the fatty acid profile of their fat (saturated or unsaturated), the disposition of fatty acids either as free or esterified to glycerol as in triacylglycerol, and their degree of rumen inertness. All of these factors can influence animal responses and composition of milk and tissue fat by altering microbial activity in the rumen, influencing fiber and carbohydrate digestion, affecting the digestibility of fat in the small intestine, and influencing appetite of dairy cows. Table 5.6 describes some key characteristics of fat sources commonly supplemented in the diet of lactating dairy cows. Some fat sources are products of the animal rendering industry, such as beef tallow, porcine tallow, and poultry fat. These fat sources are in the form of triacylglycerols with a small but variable proportion of free fatty acids depending on how they are handled. In some countries in South America, the European Union, and Japan, animal fats cannot be added to the diet of ruminants because of concerns of residues containing nervous tissues that hold a potential for the spread of bovine spongiform encephalopathy. In the United States, as of today, the use of animal fats, even those of ruminant origin such as beef tallow, is considered safe, and they are allowed to be included in ruminant diets.

Vegetable oils are commodity fats that are often incorporated into grain mixes prepared by feed mills or blended with animal fats for delivery to commercial farms. There is concern with incorporation of vegetable oils into ruminant rations because of their fast rate of microbial lipolysis of the triacylglycerol in the rumen, which makes their high content of unsaturated fatty acids susceptible to microbial biohydrogenation and to influencing fibrolytic activity in the rumen. On the other hand, when oilseeds are fed to dairy cows in moderate amounts to increase the dietary fat in 1–2 percentage units of the diet DM, their oil content usually has little impact on rumen fermentation and diet digestibility. The slower rate of release of the triacylglycerol into the rumen fluid is thought to reduce the rate of lipolysis and minimize the impact of unsaturated fatty acids on microbial activity. This is better characterized in the case of whole cottonseed, which has a hard seed coat and high fiber content, thereby slowing the release of fatty acids in the rumen and providing additional effective fiber to the diet, which usually improves rumen health.

A third group of fat sources are those called commercial fats, which were originally designed to be more rumen inert and, more recently, to supply specific fatty acids to the diet of dairy cows with less impact on rumen fermentation in an attempt to influence animal responses, primarily immune function and reproduction. In some specific milk markets, it is desirable to reduce milk fat concentration by dietary means that do not disturb microbial fermentation. Some forms of calcium salts containing mostly *trans*monoenoic fatty acids (C18:1 mostly trans) have the ability to moderately suppress milk fat synthesis without altering milk production, which allows producers in these markets to sell more fluid milk when quotas are based on the total amount of fat that can be produced. Commercial fat sources are either mostly saturated fatty acids in the form of triacylglycerols or free fatty acids. Most of the nutritional value of supplemental fats is based on its digestible energy, and digestibility of fatty acids declines when fat sources are rich in stearic acid (C18:0) in the form of triacylglycerol. On the other hand, fat sources rich in unsaturated fatty acids can have a detrimental effect on rumen microbial activity, fiber digestion, and milk composition. Therefore, when selecting a fat source, it is important to consider its digestibility, which determines the energy density in the fat source, degree of rumen inertness to minimize impacts on rumen metabolism, impacts on milk composition, and impacts on health and reproduction.

Rumen Metabolism and Digestion of Fats

Most fat sources are fed in the form of triacylglycerols. Microbial activity in the rumen is responsible for hydrolysis of the ester bond (lipolysis) between the fatty acid and the glycerol backbone. Upon release in the rumen, free fatty acids, primarily unsaturated fatty acids, are subject to microbial action (Jenkins, 1993). Because of extensive lipolysis and hydrogenation of unsaturated fatty acids in the rumen, most lipids flowing to the duodenum for absorption in the small intestine of dairy cows are in the form of saturated free fatty acids. Polyunsaturated fatty acids such as the essential fatty acids linoleic (C18:2 n6) and linolenic (C18:3 n3) acids are extensively biohydrogenated by the rumen microbes, and less than 20% of the intake of these fatty acids is available for absorption in the small intestine (Doreau & Chilliard, 1997). The rate of lipolysis is generally higher in fat sources rich in unsaturated fatty acids, which make them available to influence microbial enzymatic activity, particularly fiber digestion. Therefore, considering rumen carbohydrate fermentation, biohydrogenation of unsaturated fatty acids is a favorable process because it reduces the risk of accumulation of compounds that are potentially toxic to rumen microbes. However, when large quantities of unsaturated fatty acids are fed, the rate of lipolysis might overcome the rate of biohydrogenation, thereby resulting in accumula-

Table 5.6. Characteristics of different sources of fats used in diets of dairy cows

		DM basis (Mcal/kg or %)					% of fatty acids (FA)			
	Inert[1]	NE_L[2]	NE_L[3]	CP	NDF	FA	Saturated	Unsaturated	C18:2 n6	C18:3 n3
Animal fats										
Beef tallow	2	4.6	5.2	0	0	89	48	52	3	<1
Porcine tallow	1–2	4.6	5.2	0	0	89	39	61	10	1
Poultry fat	1–2	5.1	5.4	0	0	89	28–31	69–72	12–19	<1
Vegetable oils										
Canola oil	1	5.5	5.2	0	0	89	7	93	21	9
Corn oil	1	5.5	5.3	0	0	89	14	86	59	1
Cottonseed oil	1	5.5	5.3	0	0	89	27	73	50	<0.5
Linseed oil	1	5.5	5.2	0	0	89	33	67	16	55
Soybean oil	1	5.5	5.3	0	0	89	16	84	54	7
Yellow grease	1	5.5	5.2	0	0	89	40	60	14	1
Oilseeds										
Canola	1	3.5	3.2	20–26	16–18	35–38	7	93	21	9
Cottonseed	2	1.9	1.8	19–22	45–50	17–19	27	73	50	<0.5
Linseed or flax	1	3.3	3.0	20–24	24–28	34–36	12	88	16	55
Soybean	1	2.7	2.6	40–42	13–17	13–18	16	84	54	7
Sunflower	1	3.3	3.0	18–20	23–25	35–38	10	90	66	<0.5
Commercial fats										
Ca salts of palm FA (Megalac, EnerG II, Enertia)	3	4.9	5.4	0	0	84	57	43	8	<0.5
Ca salts of palm and soybean FA (Megalac R)	2–3	4.9	5.6	0	0	84	30	70	32	4.5
Ca salts of linseed FA (FlaxTech)	2–3	4.7	5.2	0	0	81	18	82	18	47
Ca salts of safflower FA (Prequel 21)	2–3	4.8	5.3	0	0	82	13	87	70	1.3
Ca salts of trans FA (BridgeTR)	2–3	4.8	5.3	0	0	82	30	70	1	0.5
Energy booster 100	3	5.3	5.8	0	0	99	86	14	1.5	0
Energy booster H	3	4.9	5.3	0	0	90	88	12	1.5	0
Hydrogenated tallow (Alifet; Booster fat; Dairy 80; Carolac)	2–3	3.0	4.1	<3	<1	72–90	50–87	13–50	<1	<1

[1] Degree of rumen inertness based on rate of lipolysis and degree of unsaturation, both of which affect rumen microbial activity. 1 = rumen active fat; 2 = moderate degree of rumen inertness; 3 = mostly inert in the rumen.
[2] Calculated as Mcal/kg of DM at 3× the maintenance requirements of a lactating dairy cow using the NRC (2001).
[3] Calculated as Mcal/kg of DM at 3× the maintenance requirements of a lactating dairy cow using the CPM-Dairy version 3.0.10.

tion of unsaturated fatty acids in the rumen fluid, which disrupts microbial activity. Furthermore, during the steps of biohydrogenation of fatty acids, intermediate compounds of trans configuration are produced (Jenkins, 1993), some of which, known as conjugated linoleic acids (CLAs), are extremely potent in suppressing lipogenesis in the mammary gland. The end result is a potential risk of milk fat suppression.

It has been suggested that a maximum amount of unsaturated fatty acids should be fed to dairy cows to

minimize their impact on rumen metabolism. Furthermore, increased intake of unsaturated fatty acids, even when rumen fermentation is not disrupted, can affect animal performance through its hypophagic effects (Allen, 2000; Allen et al., 2009). Feed intake in dairy cows is often suppressed when fat is supplemented in the diet, and this effect is more pronounced in early lactation or when cows are fed mostly unsaturated fatty acids. The appetite in dairy cows is regulated in part by rumen fill and by signals originated from the digestive tract (Allen, 2000; Forbes, 2005; Allen et al., 2009). Feeding fat to cows influences the release of gut peptides such as cholecystokinin, glucagon-like peptide 1, and glucose-dependent insulinotropic peptide, which are thought to be hypophagic (Allen et al., 2009). Furthermore, fat feeding seems to suppress the release of ghrelin, a peptide thought to stimulate appetite. These peptides may influence appetite by direct effects on hunger and satiety centers in the brain, and also by influencing the release of insulin, glucagon, and the firing of the vagus nerve. When energy intake increases, such as in the case of consumption of dietary fat, the absorbed nutrients increase the available cellular energy (ATP) in hepatocytes, which influence Na^+/K^+ channels and result in depolarization of nerve fibers, thereby reducing the firing rate of afferent fibers of the vagus nerve (Allen et al., 2009). The change in neural communication of the vagus nerve is thought to signal satiety and suppress hunger in dairy cows. Because unsaturated fatty acids are more likely to be oxidized by hepatocytes, it is suggested that increased intestinal flow of these fatty acids can be more hypophagic than other fatty acids (Allen, 2000). Therefore, when formulating diets for dairy cows, it is important to consider the total intake of the most abundant dietary unsaturated fatty acids, namely palmitoleic (C16:1), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) acids. Typical dairy cattle diets result in intakes of unsaturated fatty acids of 300 g/day, when no fat is supplemented, up to 700 g/day, when some type of supplemental fat is added to the diet.

Incorporation of Supplemental Fats in Dairy Diets

There are limits to the total amount of fat that should be fed in lactating rations. Current feeding practices suggest that diets of lactating dairy cows should contain no more than 7% total ether extract, which corresponds to approximately 6% total dietary fatty acids. This upper limit is only suggested in diets with adequate concentrations of NDF and high forage content. As the forage content in the ration declines, the amount of total dietary fat should also be reduced. A common rule of thumb is that dairy cows should consume the same amount of dietary long chain fatty acids as the total amount of fat secreted in milk (Palmquist, 1998). For instance, a high-yielding dairy cow producing 40 kg/day of milk with 3.75% fat secretes daily 1.5 kg of milk fat. If this cow is consuming 25 kg/day of DM, then the concentration of fat in the ration should be as follows:

$$\begin{aligned}\text{Dietary fat concentration} &= 1.5 \text{ kg of milk fat/} \\ &\quad 25 \text{ kg of DM intake} \\ &= 6\% \text{ dietary fat.}\end{aligned}$$

This rule should be applied only to cows past the first 3–4 weeks postpartum. In early lactation, milk fat secretion can be substantial because of body weight losses and extensive transfer of long chain fatty acids to milk fat. Feeding high-fat diets in the first weeks postpartum can depress feed intake and reduce microbial protein synthesis. Therefore, in the first 3–4 weeks of lactation, it is prudent to limit total dietary fat concentration to <5%.

In most lactation diets, when fat is not supplemented, the ether extract content is approximately 3%, of which 70% (2% of the diet) are fatty acids. Supplementation with fat is recommended to result in total dietary fatty acid concentration of 3%–5% of the diet DM (Palmquist & Jenkins, 1980), and for that it is important to consider the type of fats used. Fat sources should be selected based on cost per Mcal of net energy and other nutrients provided in the case of oilseeds (Table 5.7), and also based on potential implications to rumen function, fiber digestion, and performance (Table 5.6).

In most cases, the initial step is to increase the fatty acid concentration of the diet in 1.5%–2% of the total DM by adding oilseeds. They tend to be the most attractive fat sources because they provide not only fat, but also protein and NDF. Inclusion of oilseed in the diet of lactating dairy cows to increase the dietary fatty acid up to 2 percentage units (e.g., from 2% to 4% of the diet DM) usually has little influence on intake, rumen fermentation, and diet digestibility. Nevertheless, there are associations between fat source and forage sources. When the diet is based mostly on corn silage and little or no grass or legume hay or silage is present, then sources of rumen active fat (see Table 5.6) tend to be detrimental to digestibility and milk fat synthesis (Onetti & Grummer, 2004). Therefore, the relationships between fat source and forage level and source cannot be ignored. Cows fed high-forage diets or diets high in alfalfa tend to be less affected by the negative impacts of supplemental fat rumen metabolism. Such diets offer more binding sites for fatty acids to be adsorbed, which reduces their availability to interact with the rumen microflora. Additionally, high-forage diets or diets based on alfalfa hay have a

Table 5.7. Comparative cost of different fat sources commonly used in diets of dairy cows

					US $	
	U.S. $[1]/1000 kg	Fatty acid, %	NE_L, Mcal/kg[2]	Other nutrients	Kg of fatty acid	Mcal of NE_L
Ca salts of palm FA	800	84	4.9	7% Ca	0.952	0.163
Beef tallow	600	89	4.6	—	0.674	0.130
Saturated free fatty acids	950	99	5.3	—	0.960	0.179
Whole cottonseed	170	18	1.9	20% CP and 47% NDF	0.944	0.089
Whole soybeans	420	17	2.7	41% CP and 16% NDF	2.471	0.156
Yellow grease	550	89	5.5	—	0.618	0.100

[1] Based on market prices observed in the years of 2009 and 2010 in the United States.
[2] Calculated as Mcal/kg of DM at 3× the maintenance requirements of a lactating dairy cow using the NRC (2001).

faster rumen turnover rate of the liquid phase, which may remove fatty acids at a faster rate from the rumen, decreasing their availability for biohydrogenation. An additional hypothesis is that high-forage diets or diets based on alfalfa increase rumen buffering and prevent a drop in pH, which seems to be important for *trans* fatty acid synthesis. A method has been suggested to calculate the amount of rumen active fat that can be included in the diet (% of the diet DM) in order to prevent problems with fiber digestibility and milk fat suppression:

$$\text{Supplemental fat (\%)} = (6 \times \text{\% diet ADF})/\text{\% unsaturation of the fat supplement.}$$

In the following example, using a diet with 20% ADF and a supplemental fat source with 50% unsaturated fatty acids, the total amount of supplemental fat suggested would be $(6 \times 20)/50 = 2.4$ percentage units. Others have suggested that the total amount of fat fed should be equal to the amount of fat produced in milk (Palmquist, 1998). Regardless of the criteria used for fat supplementation, nutritionists and veterinarians should avoid diets with excessive fatty acid content (>6% fatty acids or >7% ether extract). These guidelines are especially important when the supplemental fat is high in unsaturated fatty acids and the basal diet is low in forage, or when the forage is mostly corn silage (Onetti & Grummer, 2004). Collectively, it is advised that lactation diets supplemented with fat should contain adequate concentrations of forage NDF, typically >20% of the diet DM, and approximately 10% of the total diet should be composed of a type of forage other than corn silage, such as grass/legume hay or silage. When more than 2% of supplemental fatty acids are added to the ration, then it is important to consider fat sources that are inert in the rumen such as calcium salts and mostly saturated fatty acids. These sources allow for greater inclusion of dietary fat, up to 5%–5.5% of the diet DM as fatty acids (6%–6.5% ether extract) with minimum effect on rumen fermentation and fiber digestion. However, such concentrations of dietary fat are needed in diets of high-producing cows only past the first 3–4 weeks postpartum. Late lactation cows and those of lower production are less likely to respond with increased production to high-fat diets, but they often experience improved body weight and body condition gains. In high-fat diets, a common guideline is that one-third of dietary fat should originate from the basal ingredients such as forages, grains, and protein supplements, one-third from commodity fat sources, and one-third from commercial fat sources that are rumen inert.

Some fat sources are more accepted by cows than others. Typically, palatability of animal fats, soybean products, whole cottonseed, and saturated free fatty acids is better than that of calcium salts, and cows readily consume the former sources. When calcium salts are the choice of supplemental fat, it is suggested to gradually introduce them to the diet such that cows become accustomed to their taste. Some fats, such as tallow, oils, and yellow grease, can reduce dustiness, separation of fine particles, and sorting of diet, which is thought to improve ration palatability.

Some considerations are needed when fat is supplemented in the diet of dairy cows:

1. Select fat sources based on price, but also consider the NE_L density of the fat source, which is derived primarily from the concentration and digestibility of the fatty acids. Do not ignore potential interactions with other components in the diet, particularly when using rumen active fats.

2. Introduce cows to supplemental fats gradually by feeding a diet with moderate concentrations of total fatty acids (3%–4%) in the first 3–4 weeks postpartum, and then increasing to up to 5%–5.5% fatty acids in the diet DM after 4 weeks postpartum. Target fat intake at a similar amount to that secreted in milk of cows past 4 weeks postpartum.
3. It is critical to provide adequate amounts of forage, as well as to include a portion of the total forage as either hay or silages of grasses or legumes. Dietary forage NDF should be >20% of the diet DM, and total forage should be >40% of the diet DM. In some situations when the NDF in forages are high, the total forage content might be reduced as long as dietary NDF is maintained above 30% and forage NDF above 20%.
4. Because unsaturated fatty acids can be saponified with cations such as calcium and magnesium, the latter might have reduced digestibility, particularly magnesium, which is absorbed primarily in the rumen. Thus, it is important to provide sufficient amounts of these minerals in diets high in fat. For lactation diets, calcium concentration should be between 0.65% and 0.80% of the DM, and magnesium between 0.30% and 0.40% of the DM.
5. Although fat provides energy to the cow, rumen microbes cannot utilize long chain fatty acids as energy sources to help growth. Therefore, high-fat diets might require additional rumen undegradable protein (RUP) of a balanced amino acid profile and of high intestinal digestibility. Focus on protein sources that complement the amino acid profile of the MP of the diet.

Impact of Supplemental Fat on Milk Composition

It is well-known that dietary sources of fatty acids influence not only the fatty acid composition of milk fat but also the concentration of fat and protein in milk. Unsaturated fatty acids during the process of biohydrogenation can generate intermediates known as CLA, some of which are known to suppress lipogenesis and fatty acid desaturation activity in the mammary gland. Under certain dietary situations such as low rumen pH, presence of ionophores, and availability of unsaturated fatty acids, the rumen environment is altered, and a portion of the biohydrogenation of linoleic acid (C18:2 n6) occurs through a pathway that produces not only very bioactive intermediates, primarily *trans*-10, *cis*-12 CLA, the best-known milk fat suppressor, but also *trans*-9, *cis*-11 CLA, and *cis*-10, *trans*-12 CLA, also known to depress *de novo* synthesis of fatty acids in the mammary gland and to depress fatty acid desaturation. A common marker present in milk during situations of milk fat depression is a substantial increase in *trans*-10 C18:1. Although it does not suppress lipogenesis in the mammary gland, it is easier to detect and is almost always associated with milk fat depression.

When concentration of fat in milk is depressed by dietary means, the fatty acids that suffer the most are those synthesized *de novo* by the mammary gland, namely the short and medium chain fatty acids. Milk fat is composed by *de novo* synthesized fatty acids originated from lipogenesis, and also by incorporation of preformed fatty acids from blood NEFA and lipoproteins. Fatty acids with <14 C (C4 to C14) are synthesized *de novo*, whereas C16 can originate from *de novo* synthesis, and also from uptake of preformed fatty acids. Those with 18 or more C (≥C18) result from uptake from blood. During milk fat depression caused either by feeding polyunsaturated fatty acids or by other means, the concentrations of C4 to C14 fatty acids, those synthesized *de novo*, and also C16 decrease, and, to a lesser extent, those containing 18 or more C.

To avoid milk fat depression the following is advised:

1. Feed good quality forages to provide a minimum amount of forage NDF to maintain rumen pH and rumen health.
2. Feed processed grains to maximize rumen starch digestion, but avoid excessive amounts that can induce low rumen pH. It is suggested that in most diets for lactating cows, the starch content should be between 20% and 26% of the diet DM.
3. Avoid excessive intake of polyunsaturated fatty acids such as linoleic (C18:2 n6), linolenic (C18:3 n3) acids, and those fatty acids present in fish oil and algae such as eicosapentaenoic (C20:5 n3) and docosahexaenoic (C22:6 n3) acids.
4. Avoid diets that favor acidic rumen pH such as those with excessive rumen degradable starch. These diets favor shifts in microbial population and intermission in the biohydrogenation pathway.
5. Care should be taken to ensure adequate physically effective NDF or forage fiber. Otherwise, these diets lead to more acidic rumen pH because of reduced buffering of the rumen by saliva, reduced rumen contractions important for VFA absorption, and reduced adsorption of fatty acids to fiber particles, making them more available to lipolysis and biohydrogenation. It is critical that both adequate forage and forage particle size be present in diets of dairy cows to prevent depression in milk fat.
6. Diets should include rumen buffers and alkalinizing agents. Inclusion of buffers such as sodium bicarbon-

ate and sesquicarbonate, and alkalinizing agents, such as magnesium oxide, maintain a more adequate rumen pH, which prevents the accumulation of trans fatty acids in the rumen.

7. Avoid feeding large quantities of ionophores, particularly in diets high in starch and unsaturated fats. Ionophores shift microbial fermentation by targeting gram-positive bacteria. In this process, they disrupt the biohydrogenation pathway and favor the production of trans fatty acids in the rumen.

When dealing with milk fat depression, all of the above factors should be considered; correction of the problem usually involves manipulation of one or more of those components.

Adding fat to lactation diets usually lowers the concentration of protein in milk, particularly casein. Although protein concentration is reduced, protein yield is typically unchanged or even slightly increased as most cows respond to fat supplementation with increased milk yield (Wu & Huber, 1994). The reduction in milk protein is typically observed in cows past peak lactation, and this effect is observed regardless of the source of fatty acids used (Wu & Huber, 1994). Nevertheless, fat sources that interfere with rumen fermentation can have a more dramatic impact on milk protein synthesis because of reduction in organic matter digestion and microbial protein synthesis. The decline in milk protein concentration is typically on the order of 0.1–0.2 percentage units (4%–7% decline in concentration) and is observed soon after supplemental fat is added to the diet. It is thought that the increased efficiency of milk synthesis in cows supplemented with fat limits the uptake of amino acids by the mammary gland because of reduced blood flow per kilogram of milk produced, thereby reducing amino acid uptake and milk protein concentration. Fat feeding typically reduces insulin concentrations, and insulin has been shown to increase milk protein concentration in dairy cows. Therefore, it is possible that the limitation of amino acid uptake by the mammary gland of cows fed fat might be related to efficiency of milk synthesis as well as to hormonal modifications that limit uptake of amino acids. Another possibility is that fat feeding might reduce microbial synthesis, and microbial protein is known to have a profile of amino acids similar to that of casein and to favor milk protein synthesis (Santos & Huber, 2002; Schwab & Foster, 2009).

Benefits to Health and Reproduction

The use of fat in diets of dairy cattle usually increases the caloric density of the ration and improves lactation and reproduction, although improvements in reproduction occur in spite of provision of calories (Santos et al., 2008). Recent evidence suggests a positive effect of fat feeding during late gestation and early lactation on subsequent reproductive performance. Positive effects of feeding fat on reproduction may occur through stimulation of ovarian follicular growth, improved luteal function, and hastening of uterine involution. The effects of feeding fat early in lactation on follicular population have been observed in several studies (Santos et al., 2008). Similarly, supplementing diets of dairy cows with fat usually increases luteal concentrations of progesterone, the steroid hormone critical for blastocyst elongation and maintenance of pregnancy.

Calcium salts enriched with unsaturated fatty acids, particularly linoleic (C18:2 n6), linolenic (C18:3 n3), eicosapentaenoic (C20:5 n3), and docosahexaenoic (C22:6 n3) acids, have been implicated in benefits to reproduction. Adding fat to the diet had a small positive overall effect on fertility of dairy cows in studies summarized by Santos et al. (2008). The increase in pregnancy per insemination was of 4 percentage units. Nevertheless, it seems that greater potential exists to improve fertility when specific sources of fatty acids are used. Combinations of fatty acids of the n6 and n3 families at distinct phases of lactation might prove beneficial to pregnancy. When cows were fed 1.5% of the diet DM as calcium salts enriched in n6 fatty acids during the last weeks of gestation and first 4 weeks of lactation, and then were switched to 1.5% of the diet as calcium salts enriched in n3 fatty acids, the cumulative proportion of pregnant cows in the first two postpartum inseminations was highest (Santos et al., 2008). This benefit was observed in part because feeding n3 fatty acids during the breeding period reduced the risk of pregnancy loss. Fatty acids of the n3 family, such as linolenic (C18:3 n3), eicosapentaenoic (C20:5 n3), and docosahexaenoic (C22:6 n3), are known to suppress the synthesis of the eicosanoid prostaglandin (PG) $F_{2\alpha}$. It is possible that manipulating the pulsatility of endometrial $PGF_{2\alpha}$, among other immunomodulatory effects of n3 fatty acids, might prove beneficial to embryonic survival in cattle.

Fatty acids of the omega 6 family such as linoleic acid (C18:2 n6) are the precursor for arachidonic acid (C20:4 n6), which is the backbone of all eicosanoids, including $PGF_{2\alpha}$. It is well-known that prostaglandins and other inflammatory mediators are important for recruitment of leukocytes and production of acute phase proteins during the innate immune response. Stimulation of innate immune response by dietary n6 fatty acids has been suggested to potentially benefit uterine health of dairy cows. In experiments summarized by Santos et al. (2008), feeding calcium salts rich in linoleic acid

(C18:2 n6) did not affect the risk of retained placenta and metritis, but it reduced that of puerperal metritis (metritis with fever), suggesting a potential benefit of source of fatty acids to minimize the intensity of the disease.

On deciding to supplement diets with unsaturated fatty acids to benefit fertility, it is important not to neglect the effect of these fatty acids on rumen fermentation, fiber digestion, appetite, and milk fat synthesis. Polyunsaturated fatty acids can be fed in the diets of dairy cows but in moderate amounts. Moreover, it is important to respect the guidelines cited earlier for fat feeding and to restrict the use of polyunsaturated fatty acids to a source originated from oilseed or that is rumen inert. Finally, polyunsaturated fatty acids should be fed in moderate amounts, and when they make up most of the supplemental fat, the total dietary fat should be restricted to <5% of the diet DM.

Protein Nutrition

Fermentation of feedstuffs in the rumen-reticulum supplies substrates for synthesis of microbial protein. These include amino acids, peptides, ammonia nitrogen, and carbon skeletons. Rumen microbes are composed of 55%–65% CP based on their total nitrogen content. The concentration of CP in feedstuffs is estimated by measuring their nitrogen concentration and then multiplying this value by 6.25. This value comes from the fact that for most amino acids, nitrogen represents 16% of the molecular weight. Therefore, to convert from the analyzed nitrogen to the CP (amino acid equivalent), the value has to be multiplied by 6.25, which is calculated by dividing 100 by 16 (100/16 = 6.25).

The amino acid profile of microbial protein is very similar to that of milk protein, and the average reported concentrations of important amino acids for milk synthesis such as lysine and methionine in bacterial true protein approximate 7.9% and 2.6%, respectively (NRC, 2001). These values far exceed the concentrations of the same amino acids in nearly all feed proteins used in dairy rations. In addition to microbial protein, dairy cows utilize amino acids and peptides from the dietary protein that escapes rumen degradation. Based on intrinsic characteristics of the protein source, as well as animal factors such as DMI, proteins can either be degraded within the forestomachs or remain intact and escape rumen degradation. Research conducted in the 1960s demonstrated that lactating cows were able to produce up to 4500 kg of milk per lactation when fed diets containing no true protein (Virtanen, 1966). This demonstrates the importance of microbial protein in supplying essential and nonessential amino acids to lactating dairy cows. However, ruminal microbes do not provide enough protein for optimal milk production in high-producing dairy cows, and sufficient dietary protein must be fed to avoid ruminal degradation and supply a sufficient amount of amino acids.

Generally, dairy cattle are not efficient in converting dietary nitrogen into milk protein. Because extensive degradation of proteins within the rumen can increase nitrogen wastage and decrease efficiency of nitrogen utilization, strategies to formulate diets with protein sources that are more resistant to microbial degradation have been proposed. However, a balance between optimum microbial protein synthesis and supply of RUP with a balanced amino acid profile and of high intestinal digestibility is important for optimizing animal performance.

Because microbial protein typically represents 50%–60% of the total MP available for absorption in the small intestine of dairy cows, optimizing rumen fermentation and microbial growth usually improves yields of milk and milk protein. Microbial growth in the rumen-reticulum requires energy in the form of ATP; nitrogen in the form of NH_3, amino acids, and peptides; branched chain fatty acids; and minerals such as phosphorus, sulfur, and cobalt. In addition to nutrient supply, rumen pH, osmolarity, and outflow rate influence the growth of microbes and synthesis of microbial protein.

Energy in the form of fermentable organic matter is the key component dictating microbial protein synthesis. The NRC publication for dairy cattle (NRC, 2001) described microbial nitrogen synthesis as related linearly to the organic matter digestibility in the rumen and in the total digestive tract. Therefore, diets that supply increased concentrations of rumen-fermentable organic matter tend to improve microbial protein synthesis. Nevertheless, excessive amounts of rumen-fermentable organic matter, particularly sugars and starches, can depress rumen pH, which suppresses microbial growth, particularly the growth of those microbes that digest fiber.

Until recently, CP was the primary component for protein nutrition in ration formulation for lactating dairy cows. However, because of the increased level of productivity and increased knowledge of feed analysis and amino acid requirements, proteins have been fractionated into different categories such as CP, soluble protein, rumen degradable protein (RDP), RUP, and unavailable protein. In addition to those protein measurements, the amino acid profile of protein supplements is also important for diet formulation. Most ration formulation programs consider not only the CP content of feeds but their rumen degradability, dynamic interactions with carbohydrate sources, passage rate, and estimated amino acid profile of the rumen undegradable fraction. These considerations allow for better prediction of the amino acid flow to the small intestine of the

lactating cow. This is critical because, although the rumen microflora require protein to supply nitrogen as NH_3, amino acids, and peptides, the lactating dairy cow, like any other mammal, has no requirements for CP, but only for specific amino acids.

A minimum concentration of NH_3 nitrogen is needed to sustain rumen fermentation. In nonlactating animals, a minimum of 7%–8% CP in the diet is required for maintenance of rumen fermentation. In dairy cattle, based on *in vitro* studies, it has been estimated that a minimum concentration of 2.5 mg/dL of NH_3 nitrogen is required for optimum microbial growth. However, several studies with ruminally cannulated high-yielding dairy cows have demonstrated that the optimum NH_3 nitrogen concentration in the rumen fluid is between 10 and 20 mg/dL to maximize DMI and milk yield. It is thought that a minimum of 10%–11% of the diet DM should be RDP to assure that adequate amounts of NH_3 nitrogen, amino acids, and peptides are available to maximize microbial growth and carbohydrate digestion in the rumen (Hoover & Stokes, 1991). In fact, when soybean meal, a protein source that is mostly degradable in the rumen, was replaced by RUP sources, the flow of microbial protein declined (Table 5.8). Therefore, it is critical that RUP sources in the rations of lactating dairy cows are not incorporated at the expense of an optimum amount of degradable protein that promotes microbial growth.

Protein sources commonly used in dairy cow rations are classified according to their origins (vegetable or animal), rumen degradability, and quality, according to their essential amino acid index and intestinal digestibility. Table 5.9 depicts some features of protein sources commonly used in lactating dairy rations.

Table 5.8. Flow of nitrogen fractions to the duodenum of cows fed soybean meal or a high RUP supplement (Santos & Huber, 2002)

	Protein		Difference	
Item	Soybean meal	RUP	g/day	%
Nitrogen intake, g/day	469.1	463.6	–6.5	–1.4
Flow to the duodenum, g/day				
Microbial nitrogen	275.6	240.2	–35.4	–12.9
Feed nitrogen	201.1	248.9	47.8	23.8
Microbial and feed nitrogen	474.3	486.7	12.4	2.6
Essential amino acids	1102.0	1159.0	57.0	5.2
Lysine	230.5	138.7	–91.8	–39.8
Methionine	45.1	46.5	1.4	3.2

Table 5.9. Ruminal degradability and intestinal digestibility values of protein sources (Santos & Huber, 2002)

Protein source	CP, %	Rumen CP degradability, %	Intestinal CP digestibility, %	EAA[1] index
Rumen microbes	60	NA	80	82
Soybean meal	48–54	65	93–96	71
Alfalfa hay	18–25	70	65.7–75	65
Corn gluten meal	67	32	92–97.4	52
Distillers grains	30	48	80–84	54
Brewers grains	29	38	80–85	67
Blood meal	93	22	56.3–80	60
Feather meal	86–92	20	65–70	34
Fish meal	68–71	30	90–96	68
Meat and bone meal	45–54	48	60–78	51

[1] Essential amino acid. The higher the value, the better the quality of the protein source.

Diets for lactating dairy cows usually contain 16%–19% CP. Early lactation cows, in the first 3–4 weeks postpartum, appear to respond positively to CP percentages between 18 and 19%, probably to compensate for the lower DMI and decreased microbial protein synthesis during the first weeks postpartum. It is interesting to note that by feeding more protein to cows in early lactation, the stimulatory effects on milk yield results in body weight loss and negative energy balance (Orskov et al., 1977). Therefore, the practice of supplying more RUP in the diet of cows in the first 4 weeks postpartum can stimulate milk yield and also body fat mobilization. Nevertheless, the first months postpartum is the period when cows respond best to supplemental RUP sources that complement the synthesis of microbial protein.

Once DMI has increased and cows have passed the period of negative energy balance, usually after 4 weeks postpartum, the protein content of the diet can be decreased. In diets for high-producing cows after 4 weeks postpartum, there is little, if any, benefit to feed diets with more than 17.5% CP when the ration is properly balanced and the protein sources used contain an amino acid profile that complement that of microbial protein (Noftsger & St-Pierre, 2003). In some cases, no additional benefit was observed to increasing the protein content of the ration above 16.5% (Broderick, 2006).

For most lactating cow diets, microbial protein represents 50%–60% of the total MP available for absorption in the small intestine of dairy cows. It is known that the amino acid profile of microbial protein is somewhat constant and resembles that of milk protein. Because of that, ration formulation for dairy cows should optimize the contribution of microbial protein to the total MP needs of the cow, so less is needed from supplemental RUP sources. Just increasing the RUP fraction of the diet is not sufficient to improve lactation performance (Santos et al., 1998). Using the information in Table 5.9, it is clear that some protein sources have a better essential amino acid index than others. For instance, when diets are low in lysine, such as those based on corn silage, corn grain, and corn proteins, it is desirable to supplement with an RUP source rich in lysine, such as blood meal. On the other hand, when the supply of methionine is limiting, an RUP source rich in methionine such as corn gluten meal would be a good option. In any case, some protein sources have a more balanced concentration of essential amino acids that resembles that of microbial protein, such as fish meal. In fact, fish meal is one of the few protein sources that, when used to replace soybean meal, improves nitrogen efficiency (Broderick, 2006), and yields of milk and milk protein (Santos et al., 1998).

Chemical and physical treatment of protein sources can also alter their protein composition and the degree to which they can be degraded in the rumen. Soybean meal, which is normally highly degradable in the rumen, when treated with different chemical substances or extracted by extrusion or expeller-processed, can dramatically increase its undegradable fraction and become an attractive RUP source for dairy diets. It typically has an adequate concentration of lysine, but is somewhat low in methionine. Regardless of the RUP source utilized, it is critical that protein quality is considered in the formulation based on its amino acid profile and intestinal digestibility.

One option in diet formulation to optimize the flow of microbial nitrogen is to attempt to synchronize protein degradation with the availability of fermentable organic matter in the rumen. Although this has been a concept pursued by many scientists and nutritionists, it is clear that more important than providing dietary ingredients that are thought to be degraded at similar rates is to provide sources of carbohydrates that are extensively degraded in the rumen. Reducing grain particle size, extensively processing sources of starch by finely grinding, or steam-flaking increases ruminal starch digestion and increases microbial protein formation (Theurer et al., 1999), as long as ruminal pH is not depressed excessively.

In addition to formulating diets to maximize microbial protein synthesis and to supplement with RUP sources of high intestinal digestibility and of good amino acid profile, optimum concentrations of amino acids that are limiting for productions of milk and milk protein are often not achieved. For most diets based on corn silage and alfalfa, methionine and lysine are important limiting essential amino acids. On the other hand, it is well recognized that histidine is the first limiting amino acid for milk protein synthesis when grass silage and barley and oat diets are fed, with or without feather meal as a sole or primary source of supplemental RUP (Kim et al., 1999, 2000, 2001). Maximum milk protein output in lactating dairy cows is achieved when lysine and methionine represent 7.3% and 2.5%, respectively, of the total metabolizable amino acids. These values are difficult to reach with conventional diets, and more realistic estimates have been proposed for use in commercial farms (Schwab & Foster, 2009). Using the NRC (2001) software or other dynamic models such as CPM-Dairy (version 3.0.10; http://www.cpmdairy.net) or AMTS.Cattle (version 2.1.1; http://agmodelsystems.com/web3/), it is suggested that the percentage of the metabolizable amino acids as lysine and methionine should be 6.9% and 2.3%, respectively. In most high-producing cow rations, this can be achieved only if

diets are high in rumen fermentable organic matter, particularly starch; are also supplemented with high-quality RUP sources, such as fish and blood meal; and include additional rumen-protected methionine. When diets are balanced for amino acids, the efficiency of protein utilization is improved (Noftsger & St-Pierre, 2003; Schwab & Foster, 2009), and the total dietary CP concentration can be reduced (Broderick, 2006). A meta-analysis of the literature on supplementation with ruminally protected methionine indicates that both percentage and yield of milk protein is increased (Patton, 2010). On average, milk protein concentration increased 0.07%, and protein yield 27 g/day. The increase in protein yield reflected an increase in both protein concentration and milk yield.

The following are some guidelines for dietary protein formulation in diets for lactating cows to maximize protein utilization and yields of milk and milk protein, and to minimize the need for feeding diets with excessive concentrations of CP.

1. Feed good quality forage to provide a minimum amount of forage NDF to maintain rumen pH and rumen health.
2. Feed processed grains to maximize rumen starch digestion. It is suggested that in most lactation diets, starch content should be between 20% and 26% of the diet DM.
3. In addition to starch, the remainder of the nonfibrous carbohydrates should be made up of by-product sources rich in pectins, glucans, and sugars to maximize microbial protein synthesis. Approximately 5%–8% of the diet DM should be sugars and 8%–12% soluble fiber.
4. Feed approximately 10%–11% of the diet as RDP to supply adequate concentrations of NH_3 nitrogen, amino acids, and peptides for microbial growth. If needed, a small portion of the RDP can be from urea to increase the NH_3 nitrogen in the rumen. Avoid both overfeeding and underfeeding RDP. The first will not benefit lactation and will increase energy needs to dispose of the excess nitrogen. The latter limits microbial growth and can depress fiber digestion and DMI.
5. Supplement diets with RUP sources rich in lysine and methionine that are of high intestinal digestibility to reach a dietary CP content of 16.5%–17.5%. Protein sources based on soybean meal, canola meal, blood meal, and fish meal are the most commonly used because of their essential amino acid content and digestibility. When corn proteins are used, such as distiller's grains or corn gluten meal, the need for supplemental lysine will increase substantially. Avoid overfeeding RUP sources, particularly when at the expense of RDP.
6. Supplement the diet with a source of rumen-protected methionine or with isopropyl ester of the hydroxylated analog of methionine (HMBi). The latter is estimated to have 50% of the 2-hydroxy 4-methylthiobutanoic escape rumen degradation and be converted into methionine in peripheral tissues, primarily the kidneys. The desired lysine and methionine percentages of the MP should be 6.9 and 2.3, respectively, to achieve a ratio of lysine to methionine of 3:1.
7. Monitor milk urea nitrogen to assure that neither lack nor excess of protein is fed to the lactating cows. Samples should be taken from cows at peak DMI, between 3 and 5 months postpartum, and desirable target concentrations for urea nitrogen in milk should be between 10 and 16 mg/dL.

Minerals

The contribution of minerals to the total amount of DM consumed by dairy cows is low, and adequate mineral concentrations in lactating cow diets are usually attained easily when cows are fed complete rations. In fact, in many cases, the concentrations of minerals in diets fed to dairy cows are in excess of those needed for optimum production and health. The NRC (2001) utilizes an absorbable model for each mineral that takes into account the requirements for maintenance, body weight change, milk synthesis, fetal and uterine tissue accretion, and endogenous fecal and urinary losses. Once the requirements are established, the availability of the mineral in the different dietary sources is considered by using specific coefficients of absorption. The total amount of each mineral to be fed can then be determined by dividing the amount required (grams or milligrams) by the respective coefficient of absorption. Table 5.10 depicts the essential macro and trace minerals with requirements established for lactating dairy cows, their key metabolic role, problems associated with inadequate intake (deficiency and toxicity), the most common feed sources and their concentration and bioavailability of the mineral, and the recommended concentration in the ration and respective normal concentrations in body tissues.

It is important to indicate that mineral supplementation in dairy rations requires proper analysis of ingredients. Most modern laboratories utilize inductively coupled plasma–atomic emission spectroscopy (ICP-AES) to quantify most macro and some trace minerals, but other methods such as atomic absorption, molecular fluorimetry, and combustion elemental analysis are also

Table 5.10. Minerals for lactating dairy cows

Mineral	Function	Problems associated with inadequate intake and/or metabolism	Common feed sources and concentration of element	Bioavailability	Concentration in the ration	Tissue and normal concentration
Macro minerals						
Ca	Formation of bones and teeth; muscle contraction; blood clotting; major mineral in colostrum (2.0–2.3 g/L) and milk (1.0–1.2 g/L)	Rickets; hypocalcemia in the first days postpartum or seldom during estrus	Calcium carbonate (38%), limestone (20%–33%), monocalcium phosphate (15%), dicalcium phosphate (20%), tricalcium phosphate (30%)	• 30% in forages • 50%–70% in mineral sources	0.65%–0.80%	Serum, 8.5–11.0 mg/dL
P	Formation of bones and teeth; important for energy transferring as part of ATP; important for synthesis of DNA, RNA, phospholipids	Deficiency results in pica, which in some countries is a major risk factor for botulism because of bone intake; hypophosphatemia; flaccid paralysis caused by lack of blood phosphate; postparturient hemoglobinuria caused by hypophosphatemia Excess P intake can induce hypocalcemia in the first week postpartum	Monocalcium phosphate (21%), dicalcium phosphate (18.5%), tricalcium phosphate (18%)	60%–70%	0.35%–0.45%	Serum, 4.5–8.0 mg/dL
Mg	Formation of bones and teeth; important for control of muscle relaxation; cofactor in second messenger systems in cell communication	Hypomagnesemia with tetanic paralysis; low blood Mg can exacerbate signs of hypocalcemia Excess dietary Mg can cause diarrhea and reduced milk production	Magnesium oxide (54%), magnesium sulfate anhydrous (19%), or heptahydrate (9%)	Varies with intake of dietary K. It ranges from 30%–70%. Sulfate sources are more bioavailable than oxide.	0.25%–0.35% (up to 0.4% Mg might be needed in high K and diets rich in unsaturated fatty acids)	Serum, 2.0–3.0 mg/dL
K	Maintenance of electrolyte and acid–base balances; maintenance of electric potential in tissues; major electrolyte in sweat of cows; important for regulation of osmotic pressure, water balance, muscle contractions, nerve impulse transmission, and several enzymatic reactions. Major intracellular cation	Hypokalemia (serum K < 2.2 mEq/L) results in muscle weakness, muscle cramps, and cardiac arrhythmias. Cows will present flaccid paralysis, tetany, and can have respiratory depression before death. Common in dehydrated cows receiving treatment with mineralocorticosteroids; it can cause metabolic acidosis. Excess intake of dietary K can inhibit Mg absorption and result in hypomagnesemia	Potassium carbonate (55%), potassium bicarbonate (39%), potassium chloride (51%)	90%	1.0%–1.6% (upper value is desired when there is a need to supplement K to increase the cation anion balance of the diet)	Serum, 4.0–6.0 mEq/L

S	Component of tissue proteins; component of S-containing amino acids such as methionine, cysteine, homocysteine, and taurine; important for microbial protein synthesis	Deficiency reduces microbial protein synthesis, compromises appetite and synthesis of tissue proteins that require S-containing amino acids Excess of dietary S (>0.40% diet DM) interferes with Cu and Se absorption; it can induce cerebrocortical necrosis also known as polioencephalomalacia mainly when combined with high grain diets	Sulfate sources of other minerals such as calcium sulfate (17%), ammonium sulfate (24%), magnesium sulfate (13%–26%); protein sources rich in sulfur containing amino acids are important dietary sources	NRC (2001) considers S in sulfate sources 100% bioavailable. Others have suggested only 60%. S element is only 30%–35% compared with sulfate sources and should not be used as supplemental source of S.	0.20%–0.22%	Not commonly evaluated because most S in tissues is in the form of S-containing amino acids; serum can be used and normal concentrations range from 100 to 120 mg/dL
Cl	Maintenance of electrolyte and acid–base balances	Deficiency is uncommon unless cows do not receive any NaCl or develop displacement of abomasum. Hypochloremia can result in metabolic alkalosis.	Sodium chloride (61%)	90%	0.28%–0.35%	Serum, 95–110 mEq/L
Na	Maintenance of electrolyte and acid–base balances; maintenance of electric potential in tissues; important for muscle and nerve functions. Major extracellular cation	Deficiency results in craving for salt; reduced intake and production; dehydration; cardiac arrhythmia Toxicity as result of water deprivation can cause digestive and central nervous system symptoms such as regurgitation, diarrhea, colic, ataxia, blindness, and seizures	Sodium chloride (39%), sodium bicarbonate (27%), sodium sesquicarbonate (31%)	90%	0.28%–0.45% (upper value is desired when Na is supplemented to increase the cation–anion balance of the ration)	Serum, 135–155 mEq/L
Trace minerals						
Fe	Component of heme used for synthesis of hemoglobin and myoglobin; important component of oxygen carrying ability of cells	Deficiency is very uncommon in adult animals unless they suffer from blood loss or are infected with blood feeding internal parasites such as *Haemonchus placei* Toxicity is uncommon. Excess of dietary Fe can interfere with absorption of Cu and Zn. It can accumulate in tissues and increase the needs for cellular antioxidant.	Ferrous carbonate (38%), ferrous sulfate monohydrate (30%), ferrous sulfate heptahydrate (20%)	10% for most dietary sources. Oxides are unavailable	50 mg/kg. It is seldom supplemented as most lactation diets contain excess of Fe.	Serum (nonhemolyzed) or liver tissue; serum concentrations of 0.6–1.6 μg/mL

(*Continued*)

Table 5.10. (*Continued*)

Mineral	Function	Problems associated with inadequate intake and/or metabolism	Common feed sources and concentration of element	Bioavailability	Concentration in the ration	Tissue and normal concentration
Zn	Tissue integrity; component of metaloenzymes such as superoxide dismutase, component RNA polymerase, alkaline phosphatase, carbonic anhydrase, and alkaline phosphates; participates in the metabolism of carbohydrates, proteins, lipids, and nucleic acids; important for signal transduction and gene expression; influences immune response	Inadequate Zn intake reduces feed intake and growth; immunosuppression; parakeratosis; infertility Excess dietary Zn can causes skin lesions; impairs growth; nephrotoxic; digestive mucosa ulcers	Zinc sulfate (36%)	15%	45–55 mg/kg	Serum or liver tissue; serum concentrations of 0.8–1.4 μg/mL
Cu	Formation of bones; co-factor for many enzymes; component of superoxide dismutase and cytochrome c oxidase. Important for hair pigmentation, synthesis of hemoglobin, and proper collagen synthesis during bone formation and repair	Deficiency results in diarrhea, loss of hair pigmentation, abnormal growth and development of bone, improper collagen formation, anemia, and immunosuppression. Diets high in S and Mo interfere with Cu absorption and metabolism. Toxicity is a common problem because the margin of safety is only two to three times the requirements. Results in hemolytic crisis, severe gastroenteritis, and mucosal ulcers. Animals of the Jersey breed are more susceptible.	Copper sulfate (25%), copper chloride (58%), copper carbonate (55%). Oxide form is not bioavailable and should not be used as a supplemental source of Cu.	5%	12–16 mg/kg	Liver tissue is ideal, but serum can be used with caution. Normal liver Cu is 100–200 mg/kg wet tissue; normal serum Cu is 0.6–1.5 μg/mL

Mn	Formation of bones; co-factor for many enzymes; component of superoxide dismutase	Deficiency causes impaired growth, bone and skeletal abnormalities, ataxia, congenital defects	Manganese carbonate (48%), manganese chloride anhydrous (43%), manganese chloride tetrahydrate (28%), manganese oxide (60%), manganese sulfate anhydrous (60%), manganese sulfate monohydrate (32%), manganese sulfate heptahydrate (22%)	1%	45–55 mg/kg	Liver tissue, 10–24 mg/kg; whole bloods, 0.07–0.20 μg/mL
Se	Component of glutathione peroxidase enzymes; cellular antioxidant	Deficiency results to muscle dystrophy (white muscle disease), peroxidation of cell membranes, immunosuppression, increased incidence of retained fetal membranes, and mastitis Toxicity is associated with abnormal growth of hooves, hyperthermia, loss of hair, diarrhea, dyspnea	Sodium selenite (45%) and sodium selenate (37%)	NRC (2001) suggests 100%, but some studies indicate lower values, between 40 and 70%.	0.3–0.5 mg/kg (the maximum allowed amount of Se that can be supplemented in diets is 0.3 mg/kg)	Whole blood, 0.08–0.14 μg/mL; serum values are slightly lower than whole blood
I	Synthesis of thyroid hormones; energy metabolism	Deficiency causes goiter (hyperplasia of the thyroid glands), abortion and birth of weak and hairless calves, infertility Excess of dietary I can result in excess salivation, tearing, watery nasal discharge; iodine is transferred to milk, and excess dietary I can substantially increase milk concentrations	Calcium iodate (62%), potassium iodate (57%), potassium iodide (68%), sodium iodide (71%), ethylenediamine dihydroiodide (EDDI; 80%)	NRC (2001) suggests 85% for all iodine sources	0.45–0.60 mg/kg	Serum, 0.10–0.40 μg/mL
Co	Synthesis of vitamin B12 in the rumen; vitamin B12 is required for incorporation of propionate into the Krebs cycle during gluconeogenesis and participates in the methionine-folate cycle; microbial growth in the rumen and fiber digestion	Deficiency is associated with decreased feed intake, impaired energy metabolism, reduced feed efficiency, weight loss, anemia, and immunosuppression	Cobalt carbonate anhydrous (46%), cobalt carbonate hexahydrate (24%), cobalt sulfate monohydrate (33%), cobalt sulfate heptahydrate (21%)	NRC (2001) suggests 100%	NRC (2001) suggests 0.11 mg/kg. Because of the wide margin of safety and its role on microbial growth and energy metabolism, most lactating cow diets contain between 0.3 and 0.6 mg/kg	Rumen fluid Co concentration > 20 ng/mL; liver tissue concentration of vitamin B12 > 0.3 mg/kg

used. Laboratories typically offer mineral analyses for Ca, P, Mg, K, S, Na, Fe, Zn, Cu, Mn, Mo, and Co using ICP-AES, and Cl ions are measured by the titration method. Some soil laboratories offer analysis of selenium in feed samples, but one seldom finds services for iodine analysis. Avoid use of near-infrared reflectance (NIR) spectroscopy, commonly used for analysis of organic compounds, for analysis of minerals. NIR does not quantify minerals directly, but measures them based on relationships with other components.

The mineral concentration in standard concentrate feeds (corn, barley, sorghum, canola meal, soybean meal, cottonseed meal) usually is less variable than that of by-products and forages. Book values for mineral concentrations for standard concentrates are probably useful in ration formulation, but the same cannot be said for by-products and forages. When formulating a mineral premix to be incorporated into dairy rations, consider the mineral composition of the basal diet without the supplement; otherwise, overfeeding will occur. This is true for all macro minerals and those trace minerals that are routinely quantified in commercial laboratories such as Fe, Zn, Cu, Mn, Mo, and Co. Because of lack of analysis for selenium and iodine, most dairy rations are supplemented with the required selenium and iodine using either the upper legal limit of 0.3 mg/kg for selenium or the amount needed of iodine not considering the contributions from other dietary sources.

Vitamins

Vitamins are essential dietary compounds required in small quantities for proper cellular metabolism. In ruminants, vitamins are either provided by intake from the diet or by synthesis by the rumen microbes. There are 14 recognized vitamins in mammalian nutrition, but not all are required in the diet of ruminants, either because it is perceived that microbial synthesis is sufficient to provide adequate amounts to prevent deficiency or simply because not enough research is available to support supplementation in the diet.

Typically, lactating dairy diets are supplemented with specific amounts of the fat-soluble vitamins A, D, and E. Only for vitamins A and E have absolute requirements been established. Vitamin D can be synthesized endogenously if cows are exposed to sunlight, and although suggested amounts to be supplemented are indicated for dairy cows, lack of supplementation might not cause deficiency if cows are fed green forages and have access to sunlight.

Vitamin K is part of a group of quinone molecules that are important for the synthesis of proteins that participate in the blood coagulation cascade. It is a fat-soluble vitamin that is not considered essential for ruminants because of the endogenous synthesis by the gut microflora. Deficiency occurs only when animals suffer from losses of microbial flora such as after intensive treatment with broad spectrum antimicrobials for extended periods of time. When cattle are fed sweet clover, they can suffer from bleeding because of interference with vitamin K activity. Sweet clover contains a substance known as coumarin in varying amounts, but when spoiled or infected with molds, the coumarin is converted to a toxic substance called dicoumarin. Dicoumarin is structurally similar to vitamin K, and it binds to vitamin K-dependent enzymes such as vitamin K reductase and vitamin K epoxide reductase, thereby blocking the synthesis of clotting proteins. This extends the blood clotting time and can cause internal bleeding. In those cases, blood transfusion and injectable vitamin K is the suggested therapy.

Of the water-soluble vitamins, none have requirements established for lactating dairy cows. This does not mean that there is no role for supplemental vitamin B in lactating cow diets. In fact, ruminal synthesis of some B vitamins might not be sufficient for high-producing dairy cows (Zinn et al., 1987; Santschi et al., 2005; Schwab et al., 2006). It is interesting to note that reducing the amount of forage and increasing the concentration of NFC in the diet either had no effect or actually increased the apparent ruminal synthesis of B vitamins in lactating dairy cows (Schwab et al., 2006). Some of this effect was caused by an increase in DMI when cows were fed less forage and more ruminally fermentable carbohydrates. Table 5.11 summarizes data on the ruminal synthesis and degradation of B vitamins in cattle.

Although requirements have not been established for some B vitamins, there is substantial evidence today that some of these vitamins might have a role in improving the health and performance of dairy cows. For instance, supplementing the diet of dairy cows with 20 mg/day of biotin has been shown to improve lactation performance (Zimmerly & Weiss, 2001; Majee et al., 2003) and hoof health (Fitzgerald et al., 2000; Hedges et al., 2001). The biological role and recommended daily feeding of fat-soluble and water-soluble vitamins for lactating dairy cows is presented in Table 5.12.

General Guidelines for Ration Formulation

Formulating diets for lactating dairy cows goes beyond calculations of amounts of nutrients provided in each kilogram of ration offered. The success of nutritional programs requires knowledge of acceptability of the ration by the cow, feeding behavior, and the particular needs of cows at different stages of lactation. Presentation

Table 5.11. Ruminal synthesis of B vitamins and percentage of intake that escapes rumen degradation. Adapted from Zinn et al. (1987), Santschi et al. (2005), and Schwab et al. (2006)

	Ruminal synthesis		
B vitamin	mg/day	mg/kg of total tract digestible organic matter	Ruminal escape, % intake
B1 (thiamin)	26–61	8.3	22.2–52.3
B2 (riboflavin)	205.7–267	15.2	0.7–1.2
B3 (niacin)	892–2213	107.2	1.5–6.2
B6 (pyridoxine)	–14 to 29.8	5.6	59–101
Pantothenic acid	NA	2.2	22.1
Folic acid	13.0–21	0.42	2.7–3.0
Biotin	–15.5 to –1	0.79	45.2–132.5
B12 (cobalamin)	73–102.2	4.1	10.0–37.1

of the diet is very important, mainly when it refers to particle size of forages that are critical to maintain rumen health. It is not uncommon for veterinarians and nutritionists to face major discrepancies among the ration as formulated by the computer software also known as "ration in the paper," the ration presented to the cow in the feedbunk, and the ration actually consumed by the cow. Implementing programs that minimize and detect the variability of the ration from formulation to consumption by the cow is, therefore, important to assure that nutrient and ingredient intakes are achieved as originally planned.

In the process of ration formulation consider the following aspects:

1. Establish the nutrient requirements of the group of cows for which the diet is to be formulated. For that, it is important to know the stage of lactation, average body weight, and yields of milk and milk components by the cows.
2. Have accurate nutrient analyses of dietary ingredients, particularly forages and by-products that tend to have high variability in nutrient composition.
3. Evaluate at least twice weekly the DM content of wet ingredients used in the diet. This is critical as it allows accurate measurements of the exact amount of ingredients to be mixed in the ration.
4. Establish expectations for lactation performance. This is important as factors other than diet formulation have major impacts on DMI and yields of milk and milk components. For instance, the same diet formulated for cows under thermoneutral weather conditions will result in greater intake and production than when fed to cows under heat stress.
5. Establish a system to evaluate daily amounts of feed offered and refused by the different groups of cows, such that group DMI is known.
6. Evaluate mixing and presentation of the ration such that cows are offered a diet that is not easily prone to sorting and ingredient selection. Use of the Penn State Particle Separator at different points of the feedbunk when feed is delivered (beginning and end of delivery) as well as before removing orts to determine adequacy of mixing and feed selection.
7. Avoid use of low inclusion ingredients that cannot be accurately measured in the farm. To minimize mixing errors, prepare premixes with small inclusion ingredients added to grains and dry by-products that can be stored for several days. This is important particularly when these ingredients are fed to a limited number of cows that use small daily amounts of ingredients.
8. Whenever possible, tailor the diet to meet the needs of the specific group of cows. For that consider DMI, stage of lactation, and production parameters. Most dairy farms should be able to handle two to three different rations for lactating cows, a ration for the first 3 to 4 weeks in lactation, one for the high-producing cows, and one for the low-producing or late lactation cows.
9. Formulate diets based on nutrients, but always consider the ingredients that are the sources of these nutrients. Nutrient availability and use by the cow varies according to the source used.
10. Diet cost has to be considered when formulating rations. The nutrient requirements of the lactating cow can be met through several combinations of feed ingredients. However, reducing cost at the

Table 5.12. Vitamins for lactating dairy cows

Vitamin	Function	Problems associated with inadequate intake and/or metabolism	Daily dietary intake	Tissue and normal concentration
Fat soluble				
A (retinol)	Vision; gene transcription; immune function; reproduction; bone metabolism; epithelium integrity; antioxidant activity	Deficiency of vitamin A is characterized by night blindness; calves born blind; increased cerebrospinal fluid pressure; papilledema Toxicity can occur when animals are supplemented with >10-fold the requirements. Large doses during pregnancy can be teratogenic.	NRC (2001) suggests 110 IU/kg of body weight. Current literature supports the feeding of 100,000 IU/day. Requirements might decrease if cows are supplemented with β-carotene.	Serum, 0.25–9.50 μg/mL; liver, 25–100 μg/g
D_3 (1,25 $(OH)_2$ cholecalciferol)	Calcium homeostasis; induction of Ca binding protein for intracellular transport of Ca; novel roles on insulin and prolactin secretion, muscle function, cellular differentiation of skin and blood cells, and immune response	Cows consuming green forage and exposed to sunlight unlikely have need for supplemental vitamin D_3 Deficiency causes a bone disorder called rickets, characterized by reduced mineralization of bones particularly in young animals; older animals can develop osteomalacia; inadequate intake of vitamin D_3 and lack of exposure to sunlight can impair Ca absorption and predispose to hypocalcemia Hypervitaminosis D either because of excessive supplementation with vitamin D_3 or intake of calcinogenic plants (*Solanum malacoxylon*) that increase Ca and P absorption can cause mineralization of soft tissues	NRC (2001) suggests 20,000 IU/day	Serum; concentration of 25-OH-cholecalciferol in adult 0.02–0.10 μg/mL
E (tocopherol)	Important lipid-soluble antioxidant; protects cell membranes from oxidation; important for proper innate immune response; improves phagocytic cell activity	Inadequate intake of vitamin E causes muscle dystrophy (white muscle disease), particularly in diets high in polyunsaturated fatty acids; increased risk of retained placenta and uterine diseases; increased risk of mastitis; and impaired neutrophil function	2,000–4,000 IU/day in the first 3–4 weeks postpartum; 1,000 IU/day after 4 weeks postpartum	Blood plasma; >3 μg/mL
K (quinone)	Synthesis of blood clotting proteins	Deficiency can cause delayed blood clotting and internal bleedings	Synthesized by rumen and intestinal microbes. No requirements specified.	Limited information; plasma concentration of 0.5 ng/mL in animals with no signs of vitamin K deficiency

Table 5.12. (*Continued*)

Vitamin	Function	Problems associated with inadequate intake and/or metabolism	Daily dietary intake	Tissue and normal concentration
Water soluble				
B1 (thiamin)	Coenzyme in enzymatic reactions involving energy metabolism of cells; synthesis of neurotransmitters from the metabolism of glucose (acetylcholine, cathecholamine, serotonine, amino acids); passive transport of Na in nerve impulses	Cerebrocortical necrosis also known as polioencephalomalacia which can be caused by thiamin deficiency or, most commonly, by destruction of thiamin in the rumen by thiaminases or excessive administration of thiamin antagonists such as amprolium for treatment of coccidiosis	Synthesized by rumen and intestinal microbes. No requirements specified. Suggested supplementation at 150–300 mg/day.	Limited information
B2 (riboflavin)	Component of flavin adenine dinucleotide (FAD) and flavin adenine mononucleotide (FMN); transfer of H in cellular reactions	Deficiency has not been characterized in cattle; in monogastrics it causes anemia, alopecia, and inflammation of the oral cavity	Synthesized by rumen and intestinal microbes. No requirements specified. No data to support suggested feeding of vitamin B2.	Limited information
B3 (niacin)	Coenzymes of nicotinamide, NAD, and NADP; role in carbohydrate, protein, and lipid metabolism; causes vasodilation and can influence body temperature	Deficiency results in dermatitis (pellagra); diarrhea; hepatic lipidosis	Synthesized by rumen and intestinal microbes. No requirements specified. Because of its effects on lipid metabolism, it is supplemented as a rumen-protected form at 6–12 g/day to prevent hepatic lipidosis and ketosis. Some effect on vasodilation and control of body temperature.	Limited information
B6 (pyridoxine)	Pyridoxal phosphate participates in several reactions in carbohydrate, amino acid, and lipid metabolism; synthesis of catecholamines; incorporation of iron into hemoglobin; antibody production	Reduced growth; dermatitis; alopecia; anemia; neurological symptoms; immunosuppression	Synthesized by rumen and intestinal microbes. No requirements specified. No data to support suggested feeding of vitamin B6.	Limited information
B12 (cobalamin)	Cofactor in enzyme reactions involving single-carbon transfer; propionate metabolism and incorporation into the Krebs cycle; red blood cell synthesis; neural integrity	Deficiency occurs if diets are deficient in Co or if rumen microflora is destroyed; causes megaloblastic anemia; loss of myelin in nerve cells; poor appetite, weakness	Synthesized by rumen and intestinal microbes. No requirements specified. Supplemented at 500 mg/day.	Limited information

Table 5.12. (*Continued*)

Vitamin	Function	Problems associated with inadequate intake and/or metabolism	Daily dietary intake	Tissue and normal concentration
Folic acid	Cofactors and serve as acceptors and donors of single-carbon unit transfers; cell division; DNA methylation	Deficiency causes megaloblastic anemia; birth defects such as neural tube defects in newborns	Synthesized by rumen and intestinal microbes. No requirements specified. Supplemented at 3–6 mg/day.	Limited information
Biotin	Cofactor for carboxylase enzymes in intermediary metabolism; it is involved in the tricarboxylic acid cycle, gluconeogenesis, and fat synthesis; it is important in the production and deposition of keratin in horn formation	Dermatitis; weakness; paralysis of hind legs; reduced integrity of hoof horn tissue	Synthesized by rumen and intestinal microbes. No requirements specified. Suggested supplementation at 10–20 mg/day.	Limited information
Pantothenic acid	Component of coenzyme A; activation of fatty acids for oxidative metabolism in the mitochondria	Not characterized in ruminants; impaired fatty acid metabolism; increased ketogenesis and metabolic acidosis	Synthesized by rumen and intestinal microbes. No requirements specified. No data to support suggested feeding of pantothenic acid.	Limited information
C (ascorbic acid)	Cofactor for enzyme activity; antioxidant; regenerates vitamin E; involved in the synthesis of extracellular matrix important for collagen biosynthesis; phagocytic activity of leukocytes; carnitine biosynthesis; synthesis of adrenal cortex steroids	Deficiency is rare. It can result in improper synthesis of collagen and reduced immune response; humans develop a disease called scurvy.	Synthesized from glucose by the liver. No requirements established. No data to support suggested feeding of vitamin C.	Limited information
Choline	Synthesis of phospholipids; cell membrane integrity; absorption and transport of fatty acids and cholesterol; synthesis of acetylcholine; transmethylation reactions	Hepatic lipidosis; ketosis; weakness	Not a typical vitamin. No requirements established. Benefits observed when fed in a rumen-protected form at 15 g/day of choline for improved lipid metabolism and lactation performance.	Limited information

expense of production or animal health is often counterproductive. Therefore, it is critical to carefully consider the potential impact on production and health when dietary changes are made. Consistency in ration formulation and feeding management is often one of the key aspects of a successful feeding program.

Table 5.13 depicts several considerations for formulating diets for lactating dairy cows at different stages of lactation.

Feed Additives

There is a long list of feed additives used in the rations of lactating dairy cows for different purposes. In general, feed additives are typically non-nutritive compounds added to diets to improve dietary nutrient utilization, to enhance performance, and to minimize the risk of metabolic diseases. In some cases, feed additives might be nutritive compounds that are added to the diet to supplement what the ration itself cannot provide to the cow. Adesogan (2009) listed the proposed general benefits of specific feed additives used in dairy cattle rations:

1. Minimize fluctuations in rumen pH and control lactate concentration in the rumen fluid either by reducing its synthesis or by increasing its removal.
2. Reduce the risk of development of enteric diseases in neonates, such as diarrhea, and metabolic diseases in older livestock, such as ruminal acidosis, bloat, ketosis, and hypocalcemia.
3. Enhance rumen development in neonatal ruminants.
4. Improve the efficiency of ruminal energy utilization by reducing methanogenesis and increasing synthesis of milk and milk components.
5. Improve the efficiency of ruminal nitrogen utilization by reducing proteolysis, peptidolysis, and amino acid deamination, thus minimizing production and losses of NH_3 to the environment.
6. Increase ruminal organic matter and fiber digestibility.
7. Improve intermediary metabolism by reducing lipid mobilization and improving lipid export from the liver during periods of negative energy balance.
8. Improve Ca, P, and Mg metabolism by enhancing the ability of cells to mobilize minerals from bones and intestine.
9. Increase the level and efficiency of animal performance.

It is obvious that these benefits are dependent on the type of additive used. It is important to indicate that some of these additives have been extensively studied for both their mechanism of action as well as their effect on animal performance and health. A good example is the ionophore monensin, which is approved for use in cattle in most countries for the control of coccidiosis (*Eimeria zuernii*, *Eimeria bovis*, and *Eimeria auburnensis*), but in some also for control of bloat, to prevent metabolic disorders, and to improve the efficiency of milk production. Others still have limited application to dairy cow nutrition and are under experimental evaluation. Table 5.14 depicts a list of additives commonly supplemented to the diet of lactating dairy cows, their proposed mechanism of action, feeding recommendations, and expected benefits to lactation performance and health.

Feeding Frequency, Feed Bunk Management, and Feed Availability

In most dairy farms using TMR, feed is delivered to lactating dairy cows once or twice daily, although in some cases producers might opt to feed cows more often. It is critical to remove leftover feed daily so fresh feed can be delivered with less risk of early spoiling. This is particularly important in hot environments and when diets have low DM content.

The single most important factor that affects DMI in dairy cows is feed availability and access to the diet. Cows should have access to feed for at least 22 h a day to assure that the least dominant animals in the group are capable of consuming the ration *ad libitum*. In most farms, this is obtained by securing a 3%–5% of the amount offered as weigh-backs 24 h later. A method that is common in the beef industry is to score the feed bunk immediately before the next feeding cycle to determine whether sufficient amounts of DM have been offered to the cows. This is critical because underfeeding dairy cows is a serious error in dairy management, which restricts DMI in the least dominant animals, favors aggressive behavior, and reduces milk production. Daily feed bunk assessment should be adopted. A common scoring system is depicted as follows:

0: No feed left in the bunk, and there is an immediate need to readjust the amount offered.
1: Scattered feed left, approximately <3% of amount fed. The feed bunk should be monitored closely to determine if an increase in the amount offered is needed.
2: A thin layer of feed remains in the bunk, approximately 5%–10% of amount fed. The feed bunk should be monitored closely to determine if a decrease in the amount offered is needed.
3: A layer of 4–6 cm of feed left in the bunk, which approximates to 20%–25% of the amount offered. Amounts should be decreased in the next feeding cycle to avoid spoiling and wasting of feed.

Table 5.13. Considerations for diet formulation for lactating dairy cows at different stages of lactation

	Stage of lactation		
Item	First 4 weeks	Peak	Late (low production)
Forage content	Should be high, typically between 45 and 60% of the diet DM	Should be moderate, between 40 and 50% of the diet DM	Should be high, between 45 and 55% of the diet DM
Type of forage	Forage of slower rate of degradation and longer rumen retention time. Addition of 2–3 kg/day of dry forages such as hay is beneficial to reduce the risk of digestive problems.	Forage of fast degradation rate and rumen turnover. Addition of 2–3 kg/day of dry forage such as hay is beneficial to reduce the risk of digestive problems.	Forage of fast degradation rate and rumen turnover. Addition of dry forage is not critical.
Total NDF	Keep it at 30%–35% of the diet DM	Usually between 28% and 31% of the diet DM	Usually >30% of the diet DM
NDF from forage	Keep it at >21% of the diet DM. Ensure adequate particle size to improve rumen fill and reduce the risk of displacement of abomasum.	Usually between 16 and 23% of the diet DM. Avoid excess of forage NDF that might limit DMI.	Usually between 16 and 23% of the diet DM
Nonforage fiber sources	Should be used to replace starch sources and to increase the digestible NDF of the diet	Should be used to replace lower quality forages or to increase digestible NDF of the diet	Should be used to replace lower quality forages or to increase digestible NDF of the diet
Starch content	Moderate (20%–22% diet DM)	High (>22% diet DM)	Moderate to high
Degradability of starch	Moderate degradability	Highly degradable	Highly degradable
Sugars	5%–8% of the diet DM	5%–8% of the diet DM	5%–8% diet DM
Pectins and glucans	Should be used to replace starch sources	Should be used to replace lower quality forages	Should be used to replace lower quality forages
Crude protein	17%–19% of the diet DM	16%–17.5% of the diet DM	15%–16.5% of the diet DM
RDP	10%–11% of the diet DM	10%–11% of the diet DM	10%–11% of the diet DM
RUP	Sources high in lysine and methionine and of high intestinal digestibility	Sources high in lysine and methionine and of high intestinal digestibility	Sources high in lysine and methionine and of high intestinal digestibility
Limiting amino acids	Primarily lysine and methionine in diets based on corn silage, alfalfa, and corn grain. Positive response to supplementation.	Primarily lysine and methionine in diets based on corn silage, alfalfa, and corn grain. Positive response to supplementation.	Unlikely to respond to amino acid supplementation
Fat supplementation	Moderate. Keep it at <4.5% crude fat. Limit supplemental fatty acids to less than 1.5% of the diet DM. It can suppress intake.	Moderate to high. Keep it at 4%–6% crude fat. Use rumen-inert sources when supplementation elevates dietary fat to >4.5% of the diet DM.	Moderate to high. Keep it at 4%–6% crude fat. Use rumen-inert sources when supplementation elevates dietary fat to >4.5% of the diet DM.
Macrominerals	See guidelines in Table 5.11	See guidelines in Table 5.11	See guidelines in Table 5.11
Trace minerals	See guidelines in Table 5.11	See guidelines in Table 5.11	See guidelines in Table 5.11
Vitamins	Supplement vitamins A, D, and E as suggested in Table 5.12. Choline and biotin might be beneficial.	Supplement vitamins A, D, and E as suggested in Table 5.12. Biotin might be beneficial.	Supplement vitamins A, D, and E as suggested in Table 5.12

Table 5.14. Commonly used feed additives in the diets of lactating dairy cows

Additive	Mechanism of action	Indication	Feeding recommendation	Effects intake and diet digestibility	Effects on lactation and health	Research and field utilization
Rumen-protected choline	Source of choline for phospholipid synthesis that is needed for absorption and transport of fatty acids and cholesterol. Required for synthesis of acetylcholine. Transmethylation reactions.	Improves energy metabolism in early lactation and milk yield. Reduces the risk of ketosis and fatty liver.	Daily intake of 10–20 g/day of choline as rumen-protected source	Possibly none	Improvements in milk yield and milk fat content. Reduction ketosis and fatty liver.	Extensive
Rumen-protected niacin	Suppresses lipid mobilization by inhibiting lipolytic enzymes in the adipose tissue. Causes peripheral vasodilatation, which increases heat exchange.	Reduces fat mobilization and risk of ketosis. Minor effects in reducing body temperature in cows under heat stress.	Daily intake of 6–12 g/day of niacin as rumen-protected source	Possibly none	Minor improvements in milk yield and milk fat content. Potentially more beneficial to overconditioned and early lactation cows at high risk of ketosis.	Moderate
Biotin	It is a cofactor in carboxylation reactions in intermediary metabolism. It is involved in the tricarboxylic acid cycle, gluconeogenesis, and fat synthesis. It is important in the production and deposition of keratin in horn formation.	Improves claw health and milk yield	Daily intake of 10–20 mg	Some effect on fiber digestion. Minor impact on DMI.	Improvements in milk production of 1–2 kg/day. Improvements in claw health	Extensive
B-carotene	Precursor for vitamin A. It is thought to be important for the function of the corpus luteum and other reproductive tissues.	Improves reproductive performance and mammary gland health	Daily intake of 300–500 mg	Possibly none	Usually no change in milk yield and concentrations of fat and protein. Potential improvements in reproduction.	Moderate
2-Hydroxy 4-methylthiobutanoic (HMB)	Source of precursor for methionine synthesis used for production of tissue and milk protein	Improves concentrations of fat and protein in milk	Variable according to the diet and percentage of conversion into methionine. The latter is usually 5–20% only. Typically fed at 8–15 g/day.	Possibly none	Improvements in milk fat concentrations. Minor effects on milk true protein.	Extensive

(*Continued*)

Table 5.14. (*Continued*)

Additive	Mechanism of action	Indication	Feeding recommendation	Effects intake and diet digestibility	Effects on lactation and health	Research and field utilization
Isopropyl ester of the hydroxylated analogue of methionine (HMBi)	Source of precursor for methionine synthesis used for production of tissue and milk protein	Improves concentrations of fat and protein in milk	Variable according to the diet and percentage of conversion into methionine. The latter is usually 50%. Typically fed at 8–15 g/day.	Possibly none	Improvements in concentrations of fat and true protein in milk	Extensive
Rumen-protected methionine	Source of methionine for synthesis of tissue and milk protein	Improves production of milk protein and efficiency of protein utilization	Variable according to the diet. Typically fed at 8–15 g of methionine/day.	Possibly none	Increases in yields of milk and milk protein when diets are inadequate in methionine	Extensive
Rumen-protected lysine	Source of methionine for synthesis of tissue and milk protein	Improves production of milk protein and efficiency of protein utilization	Variable according to the diet. Typically fed at 10–25 g of lysine/day.	Possibly none	Potential increase in milk protein in diets deficient in lysine. Research data are lacking at this point.	Moderate
Monensin	Selectively kills Gram+ bacteria in the rumen, which favors establishment of microbial populations that produce propionate in place of acetate, butyrate, and methane. Reduces protein degradation in the rumen.	Improves efficiency of production of milk and milk components. Minimizes the risk of clinical and subclinical ketosis and displacement of abomasum.	Complete rations should contain 12–24 mg of monensin/kg of DM. Lactating cows should consume between 350 and 500 mg/day.	Minor depression in DMI. No effect on diet digestibility, although it can decrease rumen degradation of protein and DM. The improved feed efficiency with monensin results in estimated caloric increment of the diet of 2%–4%.	Increases milk yield by 0.5–1.5 kg/day. A depression in milk fat content is observed with high doses or when combined with diets low in fiber or high in unsaturated fatty acids. Minor effects on milk protein content. Reduces risk of bloat, ketosis, and displacement of abomasum.	Very extensive
Yeast culture	Possible scavenging of oxygen in the rumen. Favors growth of fungi in the rumen. Favors the growth of lactate-utilizing bacteria in the rumen. Provides organic acids and vitamins in the culture material.	Improves fiber digestion, minimizes the risk of subacute rumen acidosis, and improves yields of milk and milk components	It varies with manufacturer. It is typically fed at 15–60 g/day.	Minor positive effects on DMI and diet digestibility. Some improvements in rumen fiber digestion.	Improvements in yields of milk and milk components. Typical increment in milk of 1–1.5 kg/day.	Extensive

Live yeast	Scavenging of oxygen in the rumen. Favors growth of fungi in the rumen. Favors the growth of lactate-utilizing bacteria in the rumen.	Improves fiber digestion, minimizes the risk of subacute rumen acidosis, and improves yields of milk and milk components	It varies with manufacturer. It is typically fed at 0.5–1 g/day when fed as pure live yeast.	Minor positive effects on DMI and diet digestibility. Some improvements in rumen fiber digestion.	Improvements in yields of milk and milk components. Typical increment in milk of 1–1.5 kg/day.	Extensive
Fungal additives	Increase total and cellulolytic ruminal bacteria populations which favor rumen digestion of fiber and DM	Improve fiber digestion. Minor effects on rumen nitrogen metabolism. Appears to reduce body temperature of cows under heat stress.	3 g/day when *Aspergillus oryzae* is fed	Improvements in rate and extent of fiber digestion in the rumen. Minor improvements in DMI.	Minor improvements in milk yield. Some improvements in milk protein concentration.	Moderate
Fibrolytic enzymes	Increase fiber digestibility by stimulating degradation of cellulose and hemicelluloses in the rumen	Improve the rate and extent of fiber digestion in the rumen. Improve DMI.	Variable according to the type of enzyme, method of presentation, and manufacturer recommendation	Improvements in DMI and fiber digestion	Inconsistent response in milk yield	Moderate
Essential oils	Improve rumen fermentation by reducing protein deamination. Increase molar concentration of propionate in the rumen.	Improve protein utilization and supply of energy to the cow	0.5–1.5 g/day	Status still experimental	Status is still experimental	Experimental
Organic trace minerals—Cu as amino acid chelate	Increased bioavailability of the trace mineral either because of greater digestibility or increased tissue retention	Provides Cu in a more bioavailable form than sulfate or oxide forms	5–10 mg of organic Cu/kg of diet. Cows are typically fed 100–150 mg of Cu as organic Cu.	Typically no change when compared with a diet with equivalent amount of the same trace mineral fed as inorganic sources	Minor improvements in milk yield. Reduction in somatic cell count. Improvements in measures of immune competence.	Moderate to extensive

(*Continued*)

Table 5.14. (*Continued*)

Additive	Mechanism of action	Indication	Feeding recommendation	Effects intake and diet digestibility	Effects on lactation and health	Research and field utilization
Organic trace minerals—Zn as amino acid chelate	Increased bioavailability of Zn primarily because of increased tissue retention	Provides Zn in a more bioavailable form than sulfate or oxide forms	20–30 mg of organic Zn/kg of diet. Cows are typically fed 400–600 mg of Zn as organic Zn.	Typically no change when compared with a diet with equivalent amount of the same trace mineral fed as inorganic sources	Minor improvements in milk yield. Reduction in somatic cell count. Improvements in measures of immune competence.	Moderate to extensive
Organic trace minerals—Se as selenized yeast	Minor change in bioavailability of Se. Increased incorporation of Se into tissue proteins because it is a component of methionine or cysteine.	Provides Se in a more bioavailable form than sodium salts	0.15–0.3 mg of supplemental Se per kg of diet. Cows are typically fed 3–6 mg of supplemental Se as selenized yeast.	Typically no change when compared with a diet with equivalent amount of the same trace mineral fed as inorganic sources	No changes in milk yield. Improvements in measures of immune competence.	Moderate
Organic trace minerals—Cr as propionate	Improved insulin action and glucose disposal. May play a role on immunity.	Provides Cr to animals that might benefit such as cows in early lactation	0.5 mg of Cr/kg of diet.	Minor improvements in DMI	Minor improvements in milk yield. Improved glucose tolerance test and reduction in insulin resistance.	Moderate
Rumen buffers	Typically sodium bicarbonate or sesquicarbonate. Neutralize rumen acids and increase rumen fluid osmolarity, which is thought to increase liquid turnover rate	Increase rumen pH and improve acid base status by providing additional Na	Typically fed at 0.7%–1% of the diet DM. Cows are expected to consume 200–300 g/day.	Variable depending on the basal diet. It can improve rumen fiber digestion. Excessive amount can suppress intake.	Improve milk yield and milk fat concentration	Very extensive
Rumen alkalinizers	Typically magnesium oxide. Increase rumen osmolarity and liquid turnover rate, thereby removing acids from the rumen.	Increase rumen pH possibly by altering rumen fluid osmolarity and liquid turnover rate. Important source of Mg in the diet.	Typically fed at 0.2%–0.3% of the diet DM. Cows are expected to consume 40–60 g of MgO per day.	Variable depending on the basal diet. It can improve rumen fiber digestion. Excessive amounts cause decrease in DMI and diarrhea.	Improve milk yield and milk fat concentration	Extensive

4: A layer thicker than 7 cm of feed left in the bunk, which corresponds to more than 30% of the amount offered. Amounts should be decreased in the next feeding cycle to avoid spoiling and wasting of feed.
5: Feed untouched. Cows have not had access to the feed.

After deciding on the appropriate amount to offer, it is important to consider the frequency of feeding. Feeding frequency is important, and cows react to the delivery of new feed with feeding behavior. Increasing the frequency of feed provision increases the time and frequency cows spend in the feed bunk, resulting in cows having more equal access to feed throughout the day (DeVries et al., 2005). Feeding cows at least twice daily minimizes the intensity of diet sorting, particularly that of NDF (DeVries et al., 2005), which is critical for proper rumen function. It is important to indicate that pushing of feed did not have the same effect in stimulating cows to come to the feed bunk as did the delivery of new feed (DeVries et al., 2005). Therefore, although feed pushed out routinely at 2–3-h intervals assures that cows have access to the diet, pushing does not have the same impact as delivery of new feed to stimulate DMI (DeVries et al., 2003).

It is known that feed alley attendance by dairy cows is consistently more intense during the day until late evening, and access to feed greatly intensifies immediately after milking and delivery of new feed (DeVries et al., 2003). Based on these concepts and standard behavior of dairy cows in a confinement system, it becomes critical that cows receive feed at least twice daily, that each feeding be consistent with the time when cows return from milking so a fresh ration is available in the bunk when cows have the greatest appetite, and that feed be pushed up close to the bunk so cows do not have to fight and display aggressive behavior in order to consume the desired amounts of DM. Finally, feedbunks should be cleaned once daily, before the first daily feeding to avoid spoilage that may reduce feed intake.

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6

Reproductive Management in Dairy Cows

Julian A. Bartolome and Louis F. Archbald

Abstract

Evaluation of the interval from calving to first service, estrus detection, conception rate, pregnancy losses, and culling due to infertility allows for the evaluation of reproductive performance on dairy farms. Target reproductive parameters will depend on the characteristics of the farm related to level of production, type of management, and breeding program (continuous or seasonal). Ideally, each cow should receive the first service by a specified time after calving, based on postpartum management, level of milk production, nutrition, and economic consideration. Estrus detection aids and timed artificial insemination enhance estrus detection and insemination rates and can control the interval to first service. This chapter discusses management strategies that are available to maintain high reproductive performance in dairy farms.

Introduction

Poor reproductive performance in lactating dairy cows results in an increase of the average days in milk (DIM) of the herd, reduction of the number of heifers for replacement, and an increase in the rate of involuntary culling due to infertility with the consequent reduction of milk production (Weaver, 1986). Parameters such as pregnancy rate, culling rate of adult cows, neonatal mortality, culling rate of heifers, and age at first calving determine the reproductive efficiency and productivity of the herd. The economic impact of reducing the calving interval and culling for infertility by increasing pregnancy rate depends on the level of reproductive efficiency, and the greatest impact is observed in herds with poor reproductive performance (de Vries, 2006). This chapter discusses how to identify common causes of poor reproductive performance and how to develop a plan to solve them.

Evaluating Reproductive Performance

Reproductive efficiency of the lactating herd can be evaluated using commercial software programs that calculate various reproductive performance parameters. A common parameter used is the calving interval which is determined by the average days at first service, pregnancy rate for a 21-day period, and pregnancy losses. The interval postpartum after which a cow is inseminated is the voluntary waiting period (VWP) and is selected based on management decisions, milk production, and dry-off criteria. The target for the interval to first service should be the VWP plus 11 days with all cows detected in estrus and/or inseminated within the first 21-day period as shown in Figure 6.1. The 21-day pregnancy rate is the product of estrus detection/insemination rate (cows inseminated/cows available within 21 days) and conception rate (cows that conceived/cows inseminated within 21 days). The pregnancy rate indicates how fast in days cows become pregnant at the end of the VWP. Pregnancy losses occur between pregnancy diagnosis and parturition and contribute to extend the calving interval.

It is important to emphasize that culling rate must be considered since voluntary culling of nonpregnant cows could artificially increase pregnancy rate and reduce

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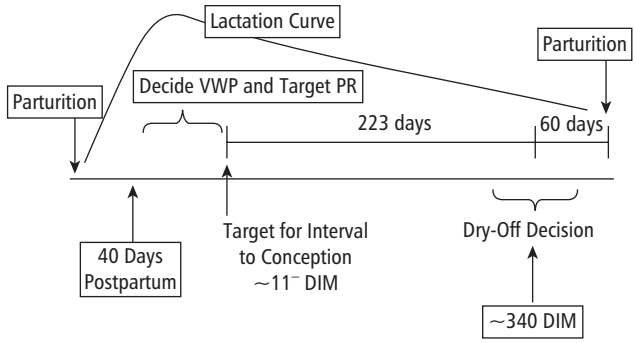

Figure 6.1. The interval from calving to first service is determined by the time of dry-off and the 21 days pregnancy rate that can be accomplished.

calving interval. Ideally, the annual culling rate should not be greater than 25% in dairy herds to maintain the number of milking cows or even be able to grow or sell heifers.

Another parameter that reflects how fast nonpregnant cows are being reinseminated and the precision of estrus detection is the interval between inseminations. It is desirable that the interval between inseminations for more than 60% of detected estrus should be between 18 and 24 days. Shorter intervals suggest inaccurate estrus detection, and longer intervals could indicate inaccuracy and inefficiency of estrus detection, ovarian abnormalities, or early embryonic mortality (Meadows, 2005).

Target parameters to evaluate reproductive performance should be established based on level of milk production of the herd and management conditions (housing, labor, etc.). Because milk production lowers the level of circulating progesterone and estrogen, and intensive management usually induces stress and reduces estrus expression, reproductive efficiency is expected to be lower in high-producing herds compared with intermediate or low-producing herds. Pasture-based dairy herds usually have seasonal breeding in order to combine maximal milk production with maximal grass production, and reproductive efficiency needs to be evaluated in one or two periods of 3 months. Target reproductive parameters for herds with continuous and seasonal breeding programs are described in Tables 6.1 and 6.2.

Clinical examination of cows using rectal palpation and/or ultrasonography should be part of the approach to evaluate reproductive efficiency, especially in herds where accurate records are not available. The list of cows to evaluate could include cows at the end of the VWP to determine if they are reproductively sound and should be bred, cows for pregnancy diagnosis, those not showing estrus by 60 or 70 DIM, previously pregnant cows that showed estrus, cows that are approximately 220 days pregnant and ready for dry-off, and cows with abnormal estrous behavior or abnormal vaginal discharge.

Cow-side evaluation of body condition score (BCS), cow identification, facilities for handling cows, and how cows are treated by the farm personnel are useful to allow proper animal handling and assurance of reproductive program compliance. The number of cows presented for pregnancy diagnosis, the number of cows inseminated during the evaluated period, and the

Table 6.1. Targeted reproductive parameters for dairy herds with continuous breeding programs (adapted from Risco & Archbald, 1999)

Parameter	Targeted value
Estrus detection rate	70%
Conception rate	40%
21-Day pregnancy rate	28%
Calving interval	13 months
Days open	115 days
Cows with interval between AI 18–24 days	>60%
Average days in milk (DIM)	155 days
Proportion of the herd becoming pregnant monthly	9%–10%[1]
Cows open more than 150 DIM	<15%
Annual culling by infertility	<10%
Annual culling rate	<25%

For herds that interrupt breeding for 1–2 months, these rates need to be adjusted proportionally (see Chapter 22 for interpretation of "pregnancy hard count" and other reproductive records).
[1] 65–70% from milking cows and 30–35% from heifers.

Table 6.2. Targeted reproductive parameters for dairy herds with seasonal breeding programs (adapted from Cavalieri et al., 2006)

Parameter	Targeted value
Cows inseminated first 3 weeks	95%
Conception rate	50%
Subsequent estrus detection/ insemination rate	80%
Cows pregnant first 45 days	75%
Total cows pregnant during breeding season	95%
Cows calving first 42 days of breeding season	<7%
Annual culling by infertility	<10%
Annual culling rate	<20%

number of cows pregnant at ultrasonography or rectal palpation can be used to calculate palpation pregnancy rate, estrus detection rate, and conception rate (Barker et al., 1994). Palpation pregnancy rate (cows pregnant over cows presented for pregnancy diagnosis) should be over 70% in herds with acceptable estrus detection rate. Additionally, estrus detection and conception rate can be calculated either for first service or subsequent services. Rectal palpation and/or ultrasonography will also allow for detection of reproductive abnormalities such as abnormal vaginal discharge, inadequate uterine involution, pregnancy losses, postpartum anestrus, ovarian cysts, endometritis, pyometra, and uterine adhesions. It is important to consider that high number of cows with postpartum anestrus and ovarian cysts will decrease palpation pregnancy rate even in herds with acceptable estrus detection rate since cows do not show estrus. Increased percentages of cows with reproductive abnormalities may indicate that the nutrition and management of the transition period should be evaluated and revised. Estimated percentages for reproductive abnormalities are described in Table 6.3.

Developing a Reproductive Program

Poor reproductive performance in lactating cows could be caused by extended interval to first service, low estrus detection/insemination rate, or low conception rate. Once the cause is identified, the factors influencing each of them and potential solutions should be considered in order to develop a reproductive program to improve reproductive efficiency.

Table 6.3. Target levels of reproductive abnormalities for confined high-producing or pasture-based low-producing dairy herds

Item	Confined herds	Pasture-based herds
Abnormal discharge or slow uterine involution at the end of VWP	<5%	<2%
Pregnancy losses between 35 and 100 days	<10%	<5%
Pregnancy losses between 100 days and dry-off	<5%	<2%
Postpartum anestrus	<2%	<10%
Ovarian cysts	<15%	<5%
Endometritis[1]	<20%	<10%
Pyometra	<0.5%	<0.5%

[1] Clinical endometritis between 20 and 30 days postpartum.

Controlling the Interval from Calving to First Service

The voluntary waiting period is the time between parturition and the time cows are allowed to be inseminated. Complete uterine involution takes approximately 40 days, and cows could be inseminated after this period. However, insemination of cows as early as possible after parturition is not always the answer since profitability could be reduced if high-producing cows become pregnant too early (de Vries, 2006). In addition, fertility increases with DIM and reaches a maximum at approximately 75 days postpartum. Therefore, the intervals to first service should be decided upon considering these two factors. In herds with low levels of milk production, the interval from calving to first service could be around 40–45 days, and in herds with high levels of milk production, around 55–60 days. In addition, first lactation cows should be allowed an extra 10–15 days in the interval from calving to first service. However, this strategy will depend on management decisions relative to characteristics of the transition period and economic factors.

Considering all these factors, we can conclude that each cow in the herd will have an ideal time to receive first service, and the more homogeneous the herd, the easier it is to manage the time from calving to first service. When the reproductive program includes estrus detection, it is usually difficult to control the interval from calving to first service as shown in Figure 6.2, and cows will be inseminated early and late relative to the ideal time for insemination considering fertility and economic or production factors. Individual electronic identification of cows coupled with excellent estrus detection, or protocols for timed insemination, could be solutions to inseminate each cow at the right time.

In pasture-based dairy herds with seasonal breeding programs, cows are inseminated during 10 weeks, and cows that calved the first day of the calving period will be inseminated approximately 85 days postpartum. At the same time, there will be cows calving during the first 40 days of the breeding season, and some of these cows will not have sufficient time for complete uterine involution and resumption of cyclicity in order to become pregnant during the breeding season. A common management approach is to induce parturition in cows that have not calved by the first day of the breeding season so that these cows will have ample time for uterine involution and could become pregnant during the last 30 days of the breeding season (Garcia & Holmes, 1999).

In herds with continuous breeding programs and low or intermediate levels of milk production, high insemination and conception rates should be the target during the first 21 days after the voluntary waiting

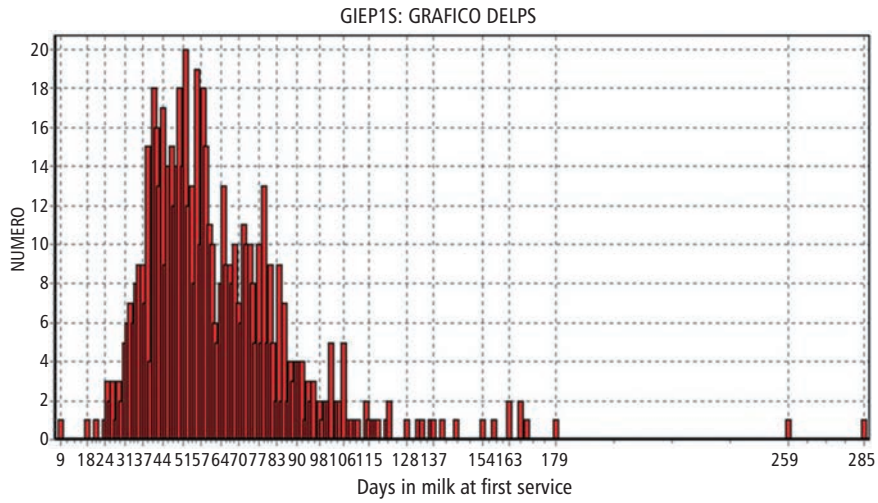

Figure 6.2. Typical interval from calving to first service (from DairyComp 305, Valley Agricultural Software©, Tulare, CA) in a herd using estrus detection for first service. Cows inseminated before 45 DIM either aborted and were not culled from the herd or have errors in their records. Cows are being inseminated early or late relative to the ideal time for first service.

period. These herds may accomplish 70% insemination rate and 40% conception rate and, by consequence, a 28% for 21-day pregnancy rate. Therefore, interval from calving to first service in pasture-based dairy herds can be controlled by optimizing estrus detection using visual observation and estrus detection aids such as pedometers, tail crayons or paints, heat mount detector devices (Kamar® Heatmount detector patches, Kamar, Inc., Steamboat Springs, CO), or the HeatWatch® System (DDx Inc., Denver, CO).

In herds with high level of milk production and intensive management, the effect of DIM on fertility is higher, and estrus detection is lower; therefore, it becomes necessary to have a strategy to control the interval from calving to first service. The Presynch-Ovsynch protocol (Moreira et al., 2001) includes two doses of prostaglandin F_2 alpha ($PGF_{2\alpha}$) 14 days apart, and then 12 days later cows are subjected to the Ovsynch protocol (gonadotropin-releasing hormone [GnRH] on Day 0, $PGF_{2\alpha}$ on Day 7, GnRH 48–56 h later, and time insemination 12–16 h after GnRH; Pursley et al., 1995). Once the interval from calving to first service is determined according to management and economic factors, the day of the first treatment with $PGF_{2\alpha}$ can be selected. Timed insemination could also be beneficial to accomplish high pregnancy rate the first days of the breeding season in herds with seasonal breeding programs or herds that interrupt breeding for a couple of months to avoid calving during the summer. In this case, protocols such as the Presynch-Ovsynch or those combining progesterone and estradiol can be used. A common protocol used in pasture-based dairy herds is administration of an intravaginal progesterone device on Day 0 in combination with 2.5 mg of estradiol benzoate, removal of progesterone device on Day 7 with a luteolytic dose of $PGF_{2\alpha}$, 1.0 mg of estradiol benzoate on Day 8, and timed insemination 24–36 h later. Since one of the major problems in pasture-based dairy herds is postpartum anestrus, administration of 400 IU of equine chorionic gonadotropin at progesterone device removal has been shown to increase conception rate in cows with low BCS (Souza et al., 2009).

Improving Estrus Detection/ Insemination Rate

The estrus detection/insemination rate (the number of cows detected in estrus and inseminated or timed-inseminated within a 21-day period) is affected by duration and intensity of estrus, anovulatory conditions (postpartum anestrus and ovarian cysts), management or efficiency of the estrus detection methods, and use of timed insemination protocols (Stevenson, 2001).

Duration and intensity of estrus (number of mounts per estrus) are affected by milk production. Since high-producing dairy cows have lower levels of circulating estrogen (Sangsritavong et al., 2002), they have shorter duration of estrus and less number of standing events (6 h with 6 mounts) compared to low-producing cows (11 h with 9 standing events; Lopez et al., 2004). Other factors related to management conditions that reduce duration and intensity of estrus are overcrowding, unfavorable flooring (concrete, hard soil, mud, etc.), and stressful handling.

Because cows need to become pregnant during the peak lactation, they are susceptible to negative energy

balance and often develop postpartum or nutritional anestrus (Butler et al., 1981). These cows will not show estrus and will not be inseminated unless they are subjected to protocols for induction of estrus. Protocols including a progesterone device for 7 days, equine chorionic gonadotropin at device removal, and estradiol at or 24 h after device removal could induce estrus in cows with superficial postpartum anestrus. Similarly, high-producing dairy cows are susceptible to developing ovarian cysts since levels of progesterone during diestrus are low, level of stress is usually high due to intensive management, and the positive feedback of estrogen to release GnRH is compromised. These cows will not ovulate, will grow follicles in the absence of progesterone, and will not express estrus unless they are treated or spontaneously recover. Protocols such as the Ovsynch including a progesterone device during the first 7 days have been successful in cows with ovarian cysts (Bartolome et al., 2005).

Management may contribute to poor estrus detection in both large and small dairy herds, but the cause could be different in each case. Cows in large dairy herds are usually under intensive management (including being milked three times per day), have high milk production, are usually housed on concrete floors and kept in large groups. These conditions usually contribute to reduced estrus expression and, therefore, reduced detection by farm personnel. Small or pasture-based herds may also have high milk production but usually have labor problems since fewer employees are needed to take care of different activities such as milking, pasture management, and calf yard tasks. In addition, these employees need to detect estrus, sort, and inseminate cows.

Synchronization of estrus and ovulation allow for timed insemination and avoid the need for estrus detection (Stevenson, 2001). Protocols for timed insemination include the use of GnRH, estradiol and progesterone devices that control the length of the luteal phase, synchronize the follicle wave, and induce ovulation. Using timed insemination, estrus detection will not be necessary, and insemination rate becomes 100%. This approach can easily be implemented for first service, either with continuous or seasonal breeding programs. However, it is more difficult to implement for subsequent services since protocols take time and may delay interval between inseminations. Therefore, timed insemination could be an option for first service, but for subsequent services it is necessary to combine an efficient estrus detection program with strategies for early detection of nonpregnant cows and rapid resynchronization. In addition, once timed insemination protocols are implemented, it may create the impression in the personnel that estrus detection is no longer necessary, and this may compromise reproductive performance. Therefore, farm personnel should clearly understand that timed insemination will complement, but not replace estrus detection unless there is a specific program established by management to completely eliminate estrus detection.

Optimizing Conception Rate

Conception rate or pregnancy per service/artificial insemination (AI) is the number of cows that conceive among cows that are inseminated or receive natural service and is influenced by cow fertility, semen quality, bull fertility, and insemination procedures. There are several factors affecting cow fertility, including nutrition and health management of the transition period, heat stress, level of blood/milk urea nitrogen, level of milk production, parity, accuracy of estrus detection, time of insemination, and infectious agents. Adequate nutritional and health management of the transition period will determine uterine health and cyclicity at the end of the VWP. Cows that experience calving-related disorders such as milk fever and retained fetal membranes will have lower conception rate (Chebel et al., 2004). Nutritional management is reflected by BCS, and there is a clear reduction in conception when BCS is less than 2.5 (1–5 scale). Since folliculogenesis takes approximately 80 days, nutrition must be consistent and balanced to accomplish the ovulation of a viable oocyte at the time of breeding.

Cows with high milk production have lower levels of circulating progesterone (Sangsritavong et al., 2002), reduced negative feedback over luteinizing hormone (LH) pulsatility resulting in persistent follicular growth, ovulation of an aged oocyte, and reduced fertility (Mihn et al., 1994). Multiparous cows have lower conception rate than primiparous cows, and it could probably be explained by the level of milk production (Chebel et al., 2004). Synchronization of the follicular wave using GnRH enhances the chances of ovulation of a healthy oocyte in high-producing dairy cows and could increase fertility. In addition, to optimize cow fertility, insemination needs to be done at the right time in relation to ovulation. Considering 26 h from LH surge to ovulation, 6–12 h for sperm transport, 24–32 h of sperm viability, and 8–12 h of ovum viability, AI is recommended 12 h after the first standing event (A.M.-P.M. rule) (Trimberger and Davis, 1943). In high-producing dairy herds with poor estrus expression, programs including intensive estrus detection may have reduced conception rate due to inaccuracy in estrus detection. Errors in estrus detection and cow identification or sorting could

result in insemination of cows at the wrong time and reduce conception rate.

The Society for Theriogenology has established minimum motility and morphology parameters for quality of fresh and frozen semen. However, bulls with great genetic value may not have ideal semen quality or fertility but could be available for use. Additionally, semen from valuable bulls is usually packaged at the minimum concentration needed for maximum fertility of that particular bull, and this may predispose to reduce conception rate when fertility of the cows is compromised or semen handling is inadequate. Semen transport from the AI center to the farm, semen handling during insemination, and skills of the technician will also influence conception rate. Semen quality and the insemination procedure have to be monitored to ensure high conception rates. All semen storage tanks should always be monitored for adequate levels of liquid nitrogen. In addition, insemination technicians should be properly trained and periodically retrained. Hygiene of the storage place and insemination tools, temperature of the water bath and time of thawing (45–60 s at 35–37°C), preparation of the insemination gun, semen straws, and sheaths need to be constantly monitored. Adequately cleaning the perineum and the use of sanitary vaginal sheaths can increase the cleanliness of the insemination gun at the level of the external cervical orifice. Catheterization of the cervix should be fast, but gentle to reduce trauma, and semen should be deposited in the body of the uterus.

Infectious diseases can reduce conception rate or increase pregnancy losses and should be monitored. A vaccination plan should be established and the vaccines selected according to the infectious agents present in the herd or region. Diseases that can either reduce conception rate or increase pregnancy losses are campylobacteriosis and trichomoniasis (natural service), infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), brucellosis, leptospirosis, and neosporosis. There are different plans to control and eradicate these diseases, and they should be applied to insure optimal reproductive efficiency. Another noninfectious factor that may contribute to pregnancy losses is the inadequate levels of progesterone during early gestation. Treatment with either GnRH or human chorionic gonadotropin to induce accessory corpora lutea could be considered to increase levels of progesterone during early gestation in cows with very high milk production and losing BCS.

Considerations for Herds with Natural Service

Artificial insemination is the most common method used to breed dairy cows. However, despite the economic advantages of AI, the use of natural service alone or in combination with AI continues to be a common method to breed dairy cows throughout the world (Lima et al., 2009). Natural service may be simpler to implement for some producers because errors in estrus detection are avoided and therefore, the perception among producers that use natural service is that reproductive performance is better. A California study that compared calving to conception intervals for cows in AI pens with cows exposed to bulls found that cows artificially inseminated had a higher risk for pregnancy across all DIM cohorts (Overton & Sischo, 2005). In contrast, reproductive efficiency has been shown to be similar for herds that use AI or natural service (de Vries et al., 2005; Lima et al., 2009).

Selection, management, and breeding soundness evaluation of the bulls are crucial to maintain high reproductive performance in herds with natural service. Before purchasing, bulls must be subjected to a complete breeding soundness examination including physical exam, exam of the reproductive organs, and tests for infectious diseases (control of brucellosis, tuberculosis, venereal diseases, vaccination plan for viral diseases, and control of internal and external parasites). It is important to consider that bulls should be around 14 months of age, of reasonable size in relation to adult cows, and should be isolated for 40–60 days before they have contact with the herd. Other recommendations for bull management include considering reduction in fertility during the summer, reduction in breeding capacity of yearling bulls, and dangerous behavior in bulls more than 2.5 years of age (Risco et al., 1998). Bulls should be periodically checked for BCS and lameness since lactating cow ration can cause overconditioning and laminitis, and they may need rest and offered dry cow ration to recover (Risco et al., 1998). Bulls should be rotated every 14 days and used in homogeneous groups by age and other characteristics such as the presence of horns to avoid adverse bull interactions and bull behavior monitored periodically since old females may inhibit inexperienced young bulls (Risco et al., 1998). Safety is a major concern when using natural service, and the use of old bulls and bulls with bad temperament should be avoided. Also, precautions should be taken when handling or sorting bulls. The bull to open cow ratio recommended is approximately from 1:20 to 1:30, and reproductive performance should be monitored frequently (every 30 days) by rectal palpation or more precisely using ultrasonography to estimate breeding and pregnancy dates.

Computer programs that evaluate reproductive performance mentioned earlier can also be used in herds with natural service to evaluate interval from calving to conception, 21-day pregnancy rate (without differentiating estrus detection and conception rates), pregnancy

losses, percentage of cows pregnant by 150 days, and culling rate due to infertility. During evaluation of cows either by rectal palpation or ultrasonography, the proportion of cows with reproductive abnormalities such as uterine adhesions, pyometra, anestrus, ovarian cysts, and others can be useful to identify causes of infertility and to treat them accordingly. Also pregnancy reconfirmation can be used to estimate pregnancy losses during different stages of gestation.

Summary

Evaluation of the interval from calving to first service, estrus detection and conception rate, pregnancy losses, and culling due to infertility allow estimating reproductive performance. Reproductive efficiency needs to be coupled with low neonatal mortality, low mortality and culling rate of adult cows and heifers, and reduced age at first calving in order to enhance productivity of the herd. These parameters need to be evaluated in relation to management conditions and the level of milk production in order to decide how much can be invested and improved. Once the decision to revise the reproductive program is made, the cause(s) of poor reproductive performance needs to be identified. Evaluation of records obtained by specific computer programs, of cows' BCS, clinical evaluation of the reproductive tract of as many cows as possible, and of facilities and general management may assist in the identification of the cause(s) of poor reproductive performance. Several technologies and management strategies are available to control the interval to first service, to optimize estrus detection, insemination and conception rates, reduction of pregnancy losses, and culling due to infertility.

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7

Reproductive Management of Lactating Dairy Cows for First Postpartum Insemination

José Eduardo P. Santos

Abstract

Implementation of systematic breeding programs for first postpartum insemination in dairy herds have become an integral part of the reproductive management of dairy cows, and they have allowed for increased insemination rates without compromising fertility. It is known that the first 3 weeks past the end of the voluntary waiting period corresponds to the estrous cycle of greatest impact on reproduction of dairy herds. Therefore, assuring high pregnancy rate in this period is critical to optimize reproduction of dairy cows. This is related to the economic value of a pregnancy that is influenced by the day postpartum when the cow becomes pregnant, the need to manage large groups of cows without creating systems that might not be implemented due to difficulty or lack of compliance, and the need to address deficiencies in cow fertility such as poor estrous expression and detection.

Introduction

Reproductive efficiency is a major component of economic success in dairy herds. The physiological and environmental stress of high-producing dairy cows negatively affects estrous detection as well as establishment and maintenance of pregnancy. Recently, it was estimated that the average value of a pregnancy was U.S. $278 in high-producing herds in the United States; whereas the cost of a pregnancy loss was substantially greater (De Vries, 2006).

There are multitudes of issues including management, the cow's reproductive physiology and metabolism, nutrition, genetics, and diseases that influence reproduction in the dairy cow. Furthermore, consolidation of the industry with larger herds poses new challenges with implementation of reproductive programs with large number of cows. In the past, most dairy herds used reproductive programs that relied upon observation of estrus up to a certain number of days in milk (DIM), and subsequent intervention was only implemented in cows with advanced DIM and no insemination. Typically, interventions were based on palpation per rectum of the reproductive tract and a decision was made based upon detection of ovarian structures. These more traditional reproductive programs focused on finding the *problem cow* and *fixing* her; however, in systems based on artificial insemination (AI), the focus should be on finding nonpregnant cows to get them pregnant in a timely manner. Quite often, key indicators of success of conventional programs were based on averages, such as for DIM at first AI, days open, and calving interval.

Nowadays, reproductive programs have taken a slightly different approach. The goal is to be proactive and work with groups of cows. In most cases, the focus is to increase the rate at which eligible cows become pregnant and, for that, use of systematic breeding protocols have become an integral portion of reproductive management in dairy herds (Caraviello et al., 2006). Ultimately, the goals are to minimize the variation in the interval from calving to first AI, increase the rate at

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which eligible cows become pregnant and, consequently, reduce the interval from calving to pregnancy in a consistent manner.

Indicators of Reproductive Efficiency

Success of AI programs in dairy herds depends upon accurate and efficient detection of estrus; however, accuracy and efficiency of estrous detection are variable and it depends upon animal, environmental, and management factors (Lucy, 2006). For the high-producing dairy cow, the altered competence of follicles and the smaller circulating concentrations of estradiol during proestrus have been associated with reduced estrous detection rates and fertility (Wiltbank et al., 2006).

Four main factors affect reproductive efficiency in dairy herds: days postpartum at first AI, estrous detection rate, pregnancy per AI (P/AI), and pregnancy loss. As in Chapter 22, in this chapter, the estrous detection rate is defined as the number of eligible cows receiving an insemination every 21 days, which is the standard estrous cycle length for cattle. Eligible cows are those that have passed the voluntary waiting period (VWP), are not pregnant, and need to be inseminated. Pregnancy per AI is defined as the number of pregnancies divided by the number of AI, which is the typical measure of intrinsic fertility of the cow. Finally, pregnancy loss is defined as the proportion of pregnant cows that have experienced either an embryonic or fetal loss. Table 7.1 depicts an example calculation of reproductive indices for every 21-day interval past 50 DIM in a herd with 100 eligible cows for the first 134 DIM.

Of the factors outlined, days postpartum at first AI and estrous detection rate can be manipulated and controlled with a certain degree of efficacy. On the other hand, P/AI and pregnancy loss in high-producing dairy cows are, in many instances, under little human control and more difficult to impact. An additional factor, culling, can bias reproductive indices without being directly related to reproductive activities in the dairy.

In order to maintain an adequate interval from calving to pregnancy and a large proportion of the herd with a calving interval <13 months, the VWP must be limited to 60–80 days postpartum. Once insemination starts, service rate should be 100%, first insemination P/AI greater than 35%, and the rate of pregnancy at every 21-day estrous cycle above 20%. Manipulation of the interval from calving to first postpartum AI impacts reproductive efficiency in dairy cows. Extending the interval usually increases days open when 21-day cycle pregnancy rate (PR) is maintained. Ferguson and Galligan (1993) indicated that PR in the first 21 days past the end of the VWP explained 79% of the variation in calving interval of dairy cows. Such high impact is because all cows in the herd eligible for insemination have to receive a first AI. Therefore, optimizing PR at the end of the VWP is critical to improve reproductive efficiency in dairy herds. In the so-called *well-managed* high-producing herds, it is not uncommon to have 50%–55% of the lactating cows pregnant before 110 DIM, resulting in a median days open of 105 days. These numbers are usually only achieved with manipulations of the interval from calving to first AI, and improvements in service rate and P/AI.

VWP and First Postpartum Insemination

Duration of the VWP is, for the most part, a management decision that can be easily manipulated. Traditionally, it varies from 40 to 90 days postpartum in most dairy herds. Decisions on when to begin AI result from physiological windows to optimize pregnancy and economic debate as to when it is best to first inseminate cows. There have been suggestions that the best interval from calving to pregnancy in dairy herds is between 100 and 120 days postpartum. As production per cow increases, particularly when associated with increased persistence of lactation, delaying first postpartum AI and time to pregnancy has less impact on the value of the pregnancy and on the economics of the dairy (De Vries, 2006).

Table 7.1. Calculation of reproductive indices at different days in milk (DIM)

DIM	Eligible cows, *n*	Detected in estrus, *n*	Estrous detection, %	Pregnant, *n*	Pregnancy per AI, %	Pregnancy rate, %
51–71	100	50	50.0	20	40.0	20.0
72–92	80	50	62.5	20	40.0	25.0
93–113	60	30	50.0	10	33.3	16.7
114–134	50	25	50.0	9	36.0	18.0
Total	290	155	53.5	59	38.1	20.3

Insemination early postpartum usually results in smaller P/AI, and delaying first postpartum AI up to 90–100 days postpartum usually increases fertility (Tenhagen et al., 2003; Stevenson, 2006). Part of the improvement in fertility of dairy cows, as first AI is delayed past the traditional 60–70 days postpartum, originates from improved uterine health with completion of uterine involution. In addition, the prevalence of anovular cows is reduced as the lactation progresses.

Delaying first postpartum insemination to 70–90 DIM increases P/AI, but does not necessarily reduce days nonpregnant or improve overall reproductive performance of the herd. Veterinarians and dairy producers must decide what the main objective of their reproductive program is when choosing a VWP for the herd. Typically, for every 21-days lengthening of the VWP, P/AI has to increase 8%–10% units to compensate for the delay in first postpartum insemination to obtain similar days open and proportion of cows pregnant at different intervals postpartum. In other words, if the VWP of a dairy herd is 60 days, and P/AI at first insemination is 35%, delaying the VWP to 81 days postpartum has to result in an increased P/AI to 43% to maintain a similar median and mean days open. Figure 7.1 depicts an example of a dairy herd with a VWP of 50 days postpartum and a 21-day cycle PR of 15% (P/AI of 30% and 21-day estrous detection rate of 50%). Early in lactation, no cow has been inseminated and thus, 100% of the herd remains nonpregnant. As days postpartum increase, the proportion of nonpregnant cows declines. The area above the curves represents the pregnant cows, whereas the area below the curves represents the nonpregnant cows. The slope of the lines represents the rate of pregnancy. Therefore, curves that drop more abruptly and reduce the area below them indicate greater PRs.

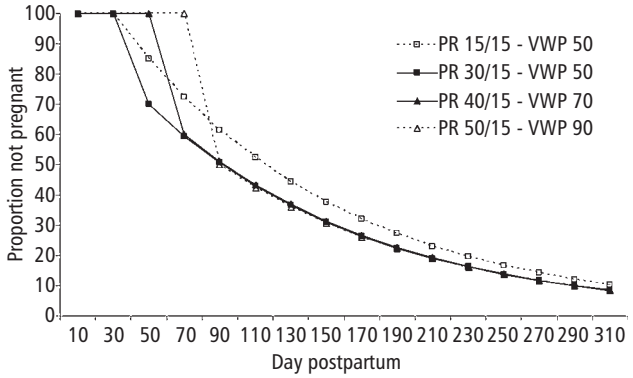

Figure 7.1. Impact of voluntary waiting period and first insemination P/AI on days nonpregnant. Legend indicates the pregnancy rate (PR) at first and subsequent AI (30/15 = 30% at first AI, and 15% thereafter) and the voluntary waiting period of 50, 70, or 90 days postpartum.

In this example, ignoring pregnancy losses and culling of cows, the expected median and mean (±SD) days nonpregnant for the average herd (21-day cycle PR of 15% and P/AI of 30%: PR15/15—VWP 50 in Figure 7.1) would be 140 and 158 ± 9 days, respectively. In the example herd, if the reproductive program is altered by increasing service rate in the first 21 days past the VWP from 50% to 100% by manipulating the estrous cycle, but P/AI is maintained at 30%, thereby resulting in first AI PR of 30%, but subsequent estrous cycles are kept at 15% 21-day PR (PR 30/15—VWP 50), then median and mean days nonpregnant change to 100 and 139 ± 8 days, respectively. When the VWP is delayed to 70 days, if P/AI increases from 30% to 40% and all cows are inseminated in the first 21 days past the VWP (PR 40/15—VWP 70), then median and mean days nonpregnant change to 120 and 143 ± 8 days, respectively. Finally, if an additional delay in VWP is implemented, now to 90 days postpartum, and P/AI increases to 50% with all cows again inseminated in the first 21 days past the VWP (PR 50/15—VWP 90), then median and mean days nonpregnant will be 100 and 156 ± 8 days, respectively. Therefore, these data illustrate that careful consideration must be taken when deciding on what the VWP should be for a given herd.

Although delaying the first postpartum AI might not maximize the proportion of pregnant cows at a specific interval postpartum, despite increased P/AI at first insemination, inseminating cows very early in lactation might not be attractive either. Likely, there is an optimum time postpartum when first AI should be performed, in which improvements in fertility and maximization of pregnant cows with adequate days open reach a balance. In reality, discussions on the optimum time to inseminate a cow have to consider its impacts on reproductive performance of the herd; risk for a cow to be culled or die with more calvings in a lifetime, as calving is the period of greatest risk for culling and death; genetic progress of the herd, as more calvings in a lifetime results in more replacement heifers; and milk yield per day of calving interval, all of which impact the economics of the decision. Generally, for cows with lactation persistence past peak milk yield of <95% (decline in milk yield of >5%/month past peak production), it is a consensus that extending the interval from calving to pregnancy reduces milk yield/day of calving interval. On the other hand, for cows with high persistence of lactation, such as primiparous, or cows with very high milk yield, becoming pregnant early can have a negative economic impact on the dairy (De Vries, 2006).

In order to illustrate the differences in control of interval to first AI, Figure 7.2 depicts scatter graphs of three different dairy herds with distinct reproductive

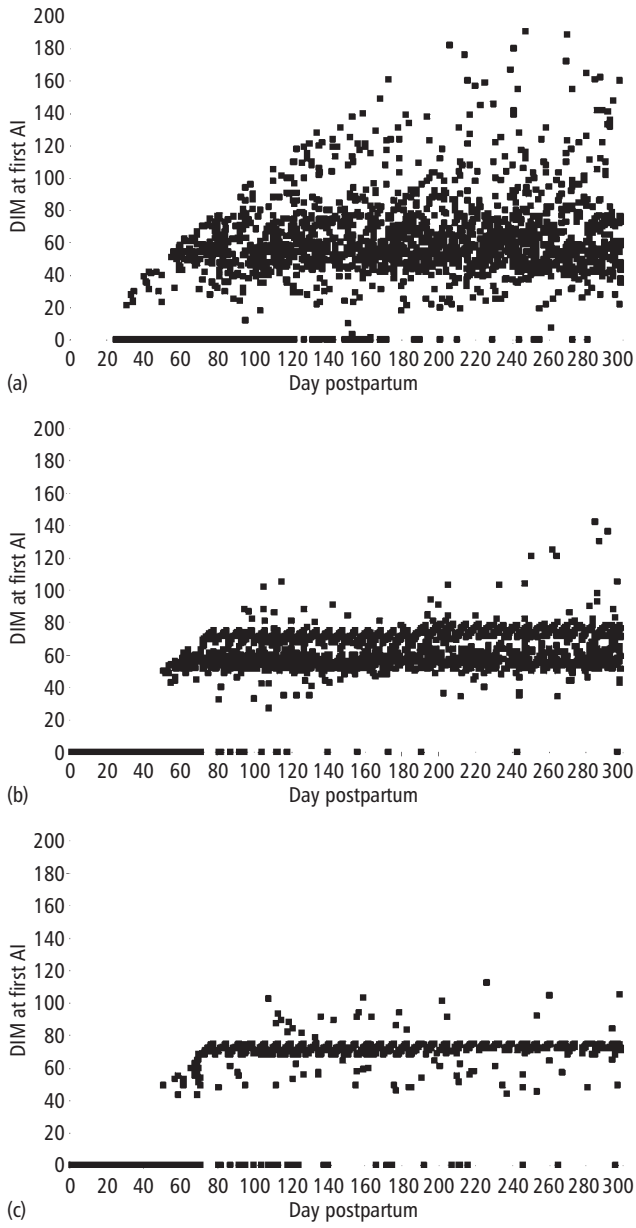

Figure 7.2. Scatter graphs of days in milk (DIM) at first AI relative to current day postpartum for cows in three dairy herds (A, B, and C). Each square represents one or more cows. Squares on the *x*-axis represent cows that have not received their first insemination in the current lactation.

management programs for first postpartum AI. Each dot represents one or more cows in the figure. Herd A has a short VWP, but it is clear that there is little control of the upper limit to DIM at first insemination. This is typical of herds that rely solely on estrous detection to inseminate cows. These herds usually begin inseminating cows early to compensate for the deficiency in estrous detection and the extended interval to first AI that some cows experience. Herd B begins to inseminate cows at approximately 50 days postpartum, but almost every cow receives the first AI no later than 80 DIM. This is typical of herds that initially rely on estrous detection for AI, but eventually cows not inseminated after a certain number of DIM are subjected to some type of timed AI program. Finally, in herd C, almost every cow receives the first AI between 65 and 75 DIM. This is typical of herds that decide not to inseminate cows early postpartum, but every cow receives the first AI following an ovulation synchronization protocol.

The approach taken by herd A as shown in Figure 7.2 is the least effective, as a large proportion of cows receive the first AI either too early or too late. Early inseminations result in poor P/AI and might compromise milk yield in current and future lactations. Cows that become pregnant very early postpartum have short lactations and may not have time to recover body condition for subsequent lactations. The approaches taken by herds B and C likely result in similar reproductive performance (Chebel & Santos, 2010). Both have advantages and disadvantages. In herd B, expenses with labor and hormones for synchronization of estrus or ovulation are reduced, although P/AI is likely to be less for cows inseminated early in the VWP than those inseminated at 70–80 DIM (Tenhagen et al., 2003; Chebel et al., 2006; Stevenson, 2006).

Generally, it is well accepted that the first postpartum AI should occur anytime between 60 and 90 days postpartum. If calving interval is to be maintained at <13 months, most herds should begin insemination sometime after 60 days postpartum, and half of the herd should be pregnant by 100–110 days postpartum.

Management of Anovular Cows

Every postpartum cow undergoes a period of anovulation; in other words, they do not present regular ovulatory periods of 18–24 days. In general, this occurs immediately after calving but, in some cows, this can extend for the first 2–3 months postpartum. In some instances, mid lactation cows can become anovular such as those that develop follicular cysts.

The delay in estrous cyclicity of postpartum dairy cows typically results in reduction in the reproductive performance of the herd because anovular cows have less estrous expression, reduced P/AI, and increased risk of pregnancy loss.

One of the characteristics of anovular cows is that they are not exposed to luteal concentrations of progesterone in the days that precede the first postpartum AI. This seems to alter the development of the ovulatory follicle, the response of the endometrium to signals that trigger the luteolytic cascade resulting in premature release of endometrial prostaglandins (PGs), and increasing the incidence of short luteal phases.

Many are the risk factors for delayed estrous cyclicity in dairy cows and, among them are the nutritional status of the cow, body condition score (BCS), parity, season of calving, occurrence of diseases at calving, the genetic makeup of the cow, and the herd of origin. It is important to indicate that within a herd or a genetic group, lactation performance seems to have little, if any association with the risk of delayed estrous cyclicity. Although milk yield is associated with changes in estrous behavior (Lopez et al., 2004), particularly a reduction in estrual activity as production increases above 35–40 kg/day, there is no indication that higher milk production impairs the ability of the cow to ovulate.

The therapy and strategies to manage anovular cows depend to a great extent on the reproductive management of the farm. Generally, the use of programs for synchronization of ovulation and timed AI associated or not with supplemental progesterone constitute the bases for the hormonal therapy.

Etiology and Classification of the Anovulatory Process in Dairy Cows

One obvious reason for lack of ovulation is the presence of progesterone blocking the luteinizing hormone (LH) surge by the pituitary. This progesterone can be of luteal or adrenal origin. Although most cows with persistent corpora lutea are pregnant and, therefore, they no longer influence the reproductive performance of the herd, there still is a small proportion of cows, 7%–10%, that have persistent corpus luteum. These cows are not pregnant, but their corpora lutea persist beyond day 25 after the last estrus and ovulation. This event seems to be more common in cows that ovulate early in the postpartum period (Ball & McEwan, 1998). In some cases, the phenomenon is associated with uterine diseases such as pyometra and the inability of the endometrium to secrete prostaglandin F_2 alpha ($PGF_{2\alpha}$) in a pulsatile fashion. These cases can be easily solved by the routine use of exogenous $PGF_{2\alpha}$ for synchronization of the estrous cycle. In fact, one of the advantages of routine use of $PGF_{2\alpha}$ between 30 and 60 days postpartum is the almost complete elimination of pyometra from dairy herds, except for cows that suffer from venereal diseases such as infections by *Tritrichomonas foetus*.

Wiltbank et al. (2002) characterized three basic physiological patterns of follicle development in dairy cows classified as anovular. The first included cows with "inactive" ovaries which were those with impaired follicle development and observation of a dominant follicle with antral diameter inferior to that typically observed in cows with a dominant follicle of ovulatory capacity. In many instances, this is called anestrus. This is a common phenomenon in postpartum beef cows, or in cows that undergo extensive feed deprivation and emaciation. It is thought that inadequate gonadotrophic support, particularly LH, results in follicle development up to 8–14 mm in diameter in lactating dairy cows. In many cases, the diameter of the largest follicle is less than that preceding follicle dominance and ovulatory capacity in dairy cows (Sartori et al., 2001).

In dairy cows, this pattern is more common in those that lost excessive amounts of body fat and have a very low BCS, particularly after periods of postpartum diseases. Likely, the major underlying factor is the low LH pulsatility that compromises the development of the dominant follicle and acquisition of ovulatory capacity. These follicles regress and undergo atresia. These cows have follicles that are not capable of secreting sufficient estradiol to increase plasma concentrations to those that can trigger surges of gonadotropin-releasing hormone (GnRH) and LH. It is suggested that the low concentrations of follicular estradiol are sufficient to block the pulsatility of GnRH and LH, thereby impeding the maturation of the dominant follicle. Because these are cows that lost excessive amounts of body fat, they might have experienced releases of progesterone from adipose tissue, which further enhances the negative feedback on the release of GnRH and LH. Furthermore, they also have inadequate concentrations of metabolic hormones such as leptin, insulin, and insulin-like growth factor-1 (IGF-1) that are critical for normal follicle development.

As the postpartum period progresses, dairy cows move from a period of negative nutritional status to resume a more favorable energy balance. Sometime in the first 4–8 weeks postpartum, most lactating dairy cows have reached positive energy and nutrient balance, and the associated hormonal and metabolic changes that encompass the period of positive energy status favor ovarian activity. Cows in a more positive energy balance have increased secretion of LH and development of follicles that can reach antral diameters greater than 15 mm. These follicles become more steroidogenic and capable of secreting larger quantities of estradiol that induces a GnRH/LH surge critical for ovulation (McDougall et al., 1995; Beam & Butler, 1999).

Although some cows develop follicles to diameters compatible with those of ovulatory follicles, many lose their dominance and regress. This second group of anovular cows represents the most prevalent pattern of anovulation postpartum (Gümen et al., 2003). Follicles from these cows reach diameters of 16–20 mm, but they do not ovulate. It is suggested that the decoupling of the growth hormone (GH) and IGF-1 system has a pivotal role to reestablish follicular steroidogenesis and the ovulatory process in dairy cows. Early lactation cows have high concentrations of GH and low of IGF-1. As feed intake increases and energy balance improves, the

concentrations of insulin in plasma also increases because of the greater flux of propionate and synthesis of glucose by the liver. The increase in plasma concentrations of insulin as energy balance improves is an important signal to reestablish the GH receptor population in the liver of cows (Butler et al., 2003). This increase in GH receptor 1A in the hepatic tissue recouples the GH/IGF-1 axis causing substantial increases in plasma concentrations of IGF-1 and enhancing the steroidogenic capacity of ovarian follicles (Butler et al., 2004).

The third pattern of follicle development in anovular cows is the cystic ovarian disease. These are cows with follicles >18 mm in diameter, many times multiple large follicles with some reaching 35 mm in diameter, but they lack a corpus luteum. This is thought to be caused by lack of positive feedback caused by estradiol on GnRH/LH surge. Gümen and Wiltbank (2002, 2005a) demonstrated that exposure to estradiol inducing an LH surge without subsequent exposure to progesterone caused the development of follicular cysts in a large portion of the dairy cows. The same authors (Gümen & Wiltbank, 2002, 2005a) and others (Nanda et al., 1991) demonstrated that cystic cows do not respond to estradiol because of refractoriness of the hypothalamus. These cows do not display signs of estrus or LH surge and ovulation upon treatment with estradiol. The underlying mechanism is lack of estrogen receptor activity in the hypothalamus, which can be restored upon exposure to progesterone.

Diagnosis of Anovular Cows

The diagnosis of anovular cows is manifest in the absence of a corpus luteum in the ovaries of cows or by the low concentrations of progesterone in plasma or serum. Therefore, lack of luteal activity characterizes an anovular cow. When ultrasonography is used, it is known that not all visualized corporal lutea reflect concentrations of progesterone that are compatible with those of cows in diestrus (Bicalho et al., 2008). Different groups of cows have distinct ovarian morphology characteristics such as diameter of follicles and corpora lutea. In the case of lactating dairy cows, the diameter of the corpus luteum that best predicted luteal concentrations of progesterone (≥1 ng/mL) was equal to or greater than 23 mm. This was the cut-point for corpus luteum diameter that resulted in highest combined sensitivity and specificity for progesterone ≥1 ng/mL (Bicalho et al., 2008).

Another option for diagnosis of anovular cows is the sequential measurements of progesterone concentrations in blood collected 7–14 days apart. This is more difficult to accomplish in veterinary practice as it requires either radioimmunoassay or enzyme-linked immunosorbent assay (ELISA) techniques. Measurements of progesterone to characterize anovular cows are typically done in research settings, and it has been the gold standard to define the population of cows with delayed estrous cyclicity. For veterinarians, ultrasonography is likely the most practical and accurate method to detect anovular cows (McDougall, 2010). It is a cow-side test that gives results immediately upon completion of the exam, but it still requires two sequential scans to be sure that the cow is truly anovular. Transrectal palpation is discouraged because of its low sensitivity and specificity to detect an active corpus luteum (Bicalho et al., 2008; McDougall, 2010). Generally, use of transrectal palpation results in misdiagnosis of 40%–60% of the cows. In other words, for every 10 known cyclic cows presented to detect an active corpus luteum, 6 will be diagnosed correctly, whereas 4 will be diagnosed as not having a corpus luteum.

Because there are periods in the estrous cycle in which cyclic cows do not have an active corpus luteum, it is therefore important to have sequential examination to certify that the prevalence of anovular cows is not inflated by those animals that might be in proestrus, estrus, or metestrus. Ideally, to minimize the number of cows in the phases of the cycle with low progesterone or without a visible corpus luteum, the diagnosis should be performed twice no less than 7 and no more than 14 days apart; otherwise, it is possible that the prevalence of anovular cows will be overestimated. A practical approach is to perform a single ultrasound examination at a strategic time in the postpartum period, when the lack of a corpus luteum or luteal activity best predicts pregnancy outcomes. In herds subjected to estrous synchronization with $PGF_{2\alpha}$ followed by programs to synchronize ovulation, the day of the first GnRH of the timed AI protocols is the ideal moment for detection of anovular cows (Silva et al., 2007; Bisinotto et al., 2010a). On this day, the sensitivity and specificity of detecting an anovular cow with a single ultrasound scan of the ovaries were 85.7 and 87.7%, respectively, with an accuracy of 87.3% (Silva et al., 2007).

Prevalence of Anovular Cows in Dairy Herds

The prevalence of anovular cows in dairy herds depends on a series of factors, one of them, perhaps the most important, the interval postpartum when the diagnosis is performed. The earlier postpartum the diagnosis is performed, the greater the prevalence of anovular cows observed. Walsh et al. (2007) evaluated the prevalence of anovular cows in 18 Canadian dairy herds using milk progesterone concentration at approximately 60 days

postpartum. The authors observed that, within herds, the prevalence ranged from 5% to 45%. Santos et al. (2009) evaluated the prevalence of anovular cows at 65 days postpartum in four large dairy herds and observed that from the 6393 cows sampled, 24.1% were classified as anovular and, among herds, the prevalence varied from 18.6% to 41.2%.

There are several risk factors for delayed estrous cyclicity in postpartum dairy cows and, among them, those that are important include parity, with primiparous having greater risk than multiparous; cows with low BCS; cows that have lost excessive BCS in the first weeks postpartum; cows that had dystocia or experienced a disease event after calving; and cows calving in the winter months (Walsh et al., 2007; Santos et al., 2009). It is important to indicate that, within a herd, more productive cows are not at a higher risk of having delayed postpartum ovulation. In fact, Santos et al. (2009) observed that lower producing cows, those with average milk yield of 32.1 kg/day in the first 3 months postpartum, were 21% less likely to have resumed ovulation by 65 days postpartum compared with cows producing 50 kg/day in the same period postpartum.

Ribeiro et al. (2009) characterized the prevalence of anovulation in Holstein ($n = 451$), Jersey ($n = 183$), and crossbred Holstein and Jersey ($n = 602$) cows in grazing systems. The prevalence was greater ($P < 0.001$) for Holsteins (31.7%) than for Jersey cows (17.5%) and crossbreds (15.8%). It is likely that in grazing systems, in which the availability of food can be limited compared with confinement systems, those cows of larger body size and greater maintenance requirements and potential for milk yield might experience an extended delay in the first postpartum ovulation.

Walsh et al. (2007) demonstrated that cows that suffered from calving difficulty, twin births, retained placenta, displacement of abomasum, and lameness in the first 66 days postpartum had a 50%–130% increased odds of delayed estrous cyclicity. This findings suggest that the health of the postpartum cow is intimately related with the ability to resume estrous cyclicity early postpartum, and cows that suffer from health problems during the periparturient period will have delayed first postpartum ovulation, which further compromises reproductive performance.

Impact of Delayed Estrous Cyclicity on Reproductive Performance of Dairy Cows

Anovular cows are expected to have a delay in the first estrus postpartum. Therefore, anovular cows likely have a greater impact on reproductive performance in herds in which reproduction is based primarily in estrous detection for insemination. This extends the interval to pregnancy and creates more variability in when cows receive their first AI and become pregnant. It is known that higher producing cows, particularly those housed on concrete floors, have estrus of shorter duration and of less activity (Lopez et al., 2004). Therefore, when anovular, these cows have a profound effect on the reproductive performance of dairy herds using primarily insemination upon detection of estrus.

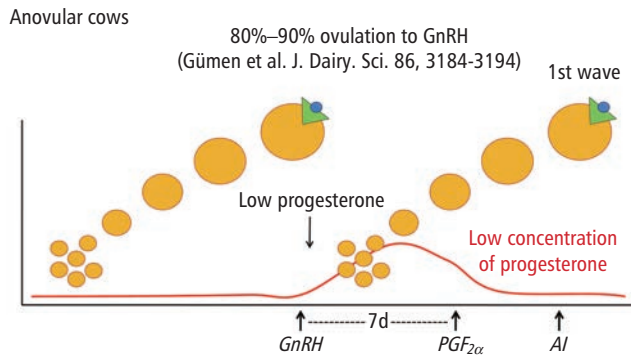

Figure 7.3. Pattern of follicle development in anovular cows subjected to timed AI programs such as the Ovsynch.

When herds use programs for ovulation synchronization that allow for timed AI, one of the characteristics of anovular cows is that they ovulate a follicle at AI that originated either from the first follicular wave, or a follicle that developed under low systemic concentrations of progesterone (Bisinotto et al., 2010a; Fig. 7.3).

Anovular cows have not been exposed to progesterone until their first ovulation. Also, their ovulatory follicles develop under low concentrations of progesterone as they are typically in metestrus and early diestrus when ovulation is induced and AI is performed (Bisinotto et al., 2010a). The development of the ovulatory follicle under low concentrations of progesterone influences the composition of the follicular fluid (Cerri et al., 2011a,b), increases the responsiveness of the endometrium to release $PGF_{2\alpha}$, which increases short estrous cycles (Cerri et al., 2011a,b), and alter embryo quality (Rivera et al., 2011). Finally, insemination of cows that have the ovulatory follicle developing under low concentrations of progesterone results in reduced P/AI (Bisinotto et al., 2010a). It is interesting to note that anovular cows have similar P/AI compared with estrous cyclic cows ovulating the first wave dominant follicle, both of which develop under low concentrations of progesterone (Bisinotto et al., 2010a).

Anovular cows not only have reduced P/AI after the first AI, but they also have increased risk of pregnancy loss (Santos et al., 2004; McDougall et al., 2005), and reduced PR (Walsh et al., 2007). Overall, the

compromised reproductive performance of these cows increases their risk to be culled from the herd.

Preventive and Therapeutic Strategies for Management of Anovular Cows in Dairy Herds

The management of cows during late gestation and early lactation is critical to minimize the risk factors that are associated with delayed estrous cyclicity. Programs that prevent metabolic diseases in early lactation, proper care during calving to reduce dystocia, and fresh cow protocols that allow for quick identification and treatment of sick cows are vital to improve reproduction in dairy herds. Implementation of these measures is expected to minimize body weight and BCS losses in early lactation as consequence of diseases.

Gong et al. (2002) demonstrated that diets rich in starch, also called glucogenic diets, increase the concentrations of insulin in early lactation, and they advance first postpartum ovulation. Nevertheless, caution is needed when excessive fermentable carbohydrates are fed because propionate is a known powerful hypophagic agent in ruminants (Allen et al., 2009). When early lactation cows received a daily injection of 75 IU of slow release insulin plus 30 g of dextrose IV in the first 14 days postpartum, interval to first ovulation was not altered, but expression of estrus was enhanced (Casas, 2010). Therefore, it is important that early lactation diets promote high caloric intake, primarily from dietary ingredients that stimulate gluconeogenesis to enhance plasma glucose and insulin. Nevertheless, these dietary manipulations should not be done at the expense of appetite and intake, otherwise, the overall caloric consumption by the cow might not be maximized. Probably, the critical point is to ensure that every cow has access to feed and is capable of consuming the largest quantity of diet possible, at the same time that a health prevention and treatment program is implemented to control and treat periparturient diseases that commonly affect dairy cows.

One method to minimize the impact of anovular cows on fertility is to delay the VWP. As the interval to first AI is extended, the prevalence of anovular cows declines, which decreases impact on fertility at first insemination. Chebel et al. (2006) demonstrated that 30% of the anovular cows on day 49 postpartum resumed estrous cyclicity at 62 days postpartum. Similarly, Lopez et al. (2005) observed that 53.9% of the anovular cows on day 71 postpartum had resumed ovulation at 100 days postpartum. Nevertheless, the delay in first AI to minimize the impact of anovular cows on P/AI may not necessarily improve the reproductive performance of the herd, as previously discussed.

Treatment with 100 μg of GnRH (gonadorelin) induces ovulation in more than 80% of the treated anovular cows (Gümen et al., 2003; Galvão et al., 2007). Therefore, an efficient method to induce ovulation and formation of a corpus luteum in anovular cows is simply to treat them with GnRH. Another strategy is to supplement progesterone. Treatment of anovular cows with intravaginal inserts containing progesterone, such as the controlled internal drug release (CIDR; EAZI-BREED™ CIDR®, Pfizer Animal Health, New York, NY), is capable of inducing estrous cyclicity in anovular cows (Gümen & Wiltbank, 2005b). Gümen and Wiltbank (2005b) demonstrated that treatment with CIDR for 3 days induced ovulation in all treated cows that had been induced to develop a cystic follicle. In studies with hundreds of anovular cows, treatment with CIDR for 7 days induced estrous cyclicity in 50%–55% of the treated cows (Chebel et al., 2006; Cerri et al., 2009a). Therefore, there still are 45%–50% of the anovular cows that are refractory to progesterone and the latter is not capable of reestablishing normal ovulatory cycles. Although inducing ovulation solves the anovular state, it does not solve the most important issue, which is to obtain a pregnancy.

After the development of protocols for synchronization of ovulation and AI at fixed time such as the Ovsynch (day 0 GnRH, day 7 $PGF_{2\alpha}$, day 9.5 GnRH, day 10 AI), it became very attractive to implement such programs for treatment of anovular cows. They induce ovulation in most of these cows (Gümen et al., 2003; Galvão et al., 2007), at the same time that insemination is performed with a reasonable P/AI. De Vries et al. (2006) indicated that the use of Ovsynch and timed AI was economically superior compared with the use of CIDR and observation of estrus for treatment of anvoular cows. More recently, McDougall (2010) also concluded that the use of timed AI, in this case the Ovsynch program combined with a CIDR, resulted in the highest economic benefit as therapy for anovular cows.

One such strategy to treat anovular cows is the combination of timed AI with supplemental progesterone. Six experiments evaluated the efficacy of supplemental progesterone during timed AI programs in anovular cows and are shown in Table 7.2. In only two of them was P/AI increased statistically (Stevenson et al., 2008). After compiling all these data, the overall improvement in P/AI of anovular cows subjected to timed AI and supplemented with progesterone was of 4.9% units (32.3% vs. 27.4%).

Another strategy is the use of methods to presynchronize the estrous cycle that also induce ovulation. These programs involve additional hormonal treatments, but the expectation is that a larger proportion of cows will be estrous cyclic and in diestrus at the beginning of the timed AI program. Chebel et al. (2006) incorporated a

Table 7.2. Effect of supplemental progesterone as controlled internal drug release (CIDR) during the timed AI programs on P/AI of anovular dairy cows

	Treatment		
	Control	1 CIDR	2 CIDR
References	% (no./no.)		
Chebel et al. (2010)	27.2 (60/221)	31.4 (70/223)	—
El-Zarkouny et al. (2004)	20.0 (5/25)	55.6 (15/27)	—
Galvão et al. (2004)	32.8 (20/61)	25.0 (13/52)	—
Lima et al. (2009)	27.6 (24/87)	29.5 (23/78)	36.5 (31/85)
Stevenson et al. (2006)	30.3 (29/96)	33.5 (30/88)	—
Stevenson et al. (2008)	24.1[a] (28/116)	32.3[b] (50/155)	—
Overall mean	27.4 (166/606)	32.3 (201/623)	—

[a,b] $P < 0.05$.

CIDR during the presynchronization of the estrous cycle. The Ovsynch program was initiated 13 days after the removal of the CIDR. The authors concluded that, although the use of CIDR improved the proportion of cyclic cows initiating the timed AI program, it was not sufficient to improve fertility at first AI. Similar results were observed by Bicalho et al. (2007), and the incorporation of the CIDR during presynchronization with $PGF_{2\alpha}$ is not warranted at the moment.

A second option is to induce ovulation with GnRH before initiating the Ovsynch program. It is expected that an injection of GnRH will induce ovulation and presynchronize the estrous cycle such that cows initiate the Ovsynch protocol in early diestrus (Bello et al., 2006). For detailed discussion, see the section on "Alternative Presynchronization Methods."

Implementing Reproductive Programs for First AI

High-producing lactating dairy cows have compromised duration and intensity of estrous expression (Wiltbank et al., 2006; Yaniz et al., 2006). Therefore, implementation of reproductive programs based on synchronization of estrus, ovulation, or both is needed to optimize reproductive efficiency in dairy herds.

Estrous Synchronization Protocols

Estrous synchronization protocols allow for insemination of cows with little control over time of insemination and the total number of cows serviced. Because estrous synchronization protocols do not control moment of ovulation, detection of estrus is required, and these protocols only become effective when estrous detection rate is good to excellent. Two major impediments for the success of programs that are based solely on estrous synchronization are the poor expression of estrus in high-producing cows and the high prevalence of anovular cows during the first 60 days postpartum (Wiltbank et al., 2006; Santos et al., 2009). Estrous expression and detection can be further compromised by environmental and animal factors such as poor footing and inadequate surface for mounting activity, lameness, and lack of individual animal attention as the industry consolidates and farms become larger with fewer employees per cow (Lucy, 2006).

Synchronization of estrus can be accomplished simply by systematic use of $PGF_{2\alpha}$. The use of $PGF_{2\alpha}$ to synchronize estrus is the most common protocol implemented in dairy farms. It consists of single or multiple injections of $PGF_{2\alpha}$ or analogs to regress a responsive corpus luteum, which causes the cow to return to estrus in 2–7 days. The corpus luteum is generally responsive to $PGF_{2\alpha}$ only after day 5 of the estrous cycle, and a single injection of $PGF_{2\alpha}$ given at random stages of the estrous cycle should induce estrus in approximately 60%–70% of the cycling cows. When two injections of $PGF_{2\alpha}$ are given 10–14 days apart, over 90% of the cycling cows are expected to respond to the second injection. However, frequency of anovular cows and lack of optimal estrous detection can have a major impact on the number of cows responding to $PGF_{2\alpha}$ and observed in estrus. On most dairy farms, utilization of two $PGF_{2\alpha}$ injections in the first 50 days postpartum results in estrous detection rates following the second injection between 50% and 60% (Bruno et al., 2005; Chebel et al., 2006). Because $PGF_{2\alpha}$ has no impact upon follicular development and, therefore, no control over follicle wave emergence, cows in this program come into estrus at different days following the injection, with little precision over time of insemination and ovulation.

Response to $PGF_{2\alpha}$ can be improved by controlling follicle growth and assuring that a responsive corpus luteum is present at the moment of treatment. Turnover of follicles can be achieved by an injection of GnRH, which induces an LH surge and ovulation of a dominant follicle with subsequent recruitment of a new cohort of follicles. However, the use of GnRH to recruit a new follicular wave is only effective when the dominant follicle is responsive to LH. Generally, follicles larger than 10 mm in diameter have undergone deviation and have developed LH receptors in the granulosa cells. This seems to be the threshold diameter for follicles to respond to LH (Sartori et al., 2001). Response to GnRH is optimum when it is administered on days 5–9 of the estrous cycle and up to 80%–90% ovulation can be achieved (Vasconcelos et al., 1999; Bello et al., 2006). When given at random stages of the estrous cycle, it is expected that 50%–60% of the treated cows will ovulate in response to GnRH. Utilization of GnRH followed 7 days later by $PGF_{2\alpha}$ is a simple program that increases response to $PGF_{2\alpha}$ and improves synchrony of estrus.

Another method to improve estrous response to $PGF_{2\alpha}$ is to combine with an intravaginal progesterone insert. Inserts, such as the CIDR, result in subluteal concentrations of progesterone in high-producing dairy cows (Cerri et al., 2009a), which are sufficient to block estrus and ovulation and increase tightness of estrous detection (Chebel et al., 2006). When combined with an injection of $PGF_{2\alpha}$, the use of progesterone inserts should be limited to no longer than 7 days to avoid persistent follicle and a reduction in subsequent fertility. The most common protocol is the insertion of the intravaginal device for 7 days, with an injection of $PGF_{2\alpha}$ on day 6 or 7. Estrous response to a combination of progesterone and $PGF_{2\alpha}$ treatment is usually high, and more than 70% of the cows that come into estrus do so between 2 and 4 days after removal of the insert and administration of $PGF_{2\alpha}$ (Chebel et al., 2006). When postpartum cows were treated with CIDR for 7 days and received $PGF_{2\alpha}$ at insert removal, distribution of estrus was altered and cows were inseminated sooner when compared with $PGF_{2\alpha}$ alone (Chebel et al., 2006). Improvements in this protocol can be attained by the addition of an injection of GnRH at the CIDR insertion to recruit a new follicular wave as shown in Figure 7.4.

Another option is the use of estrogens combined with progesterone insert and $PGF_{2\alpha}$. A commonly used program is the administration of 2 mg of estradiol benzoate concurrent with a CIDR insert. The estrogen increases concentrations of estradiol in blood, which causes atresia of the ovarian follicles. After estradiol concentrations decline, a new wave of follicle development is recruited, which occurs between 3.5 and 4.5 days after estradiol benzoate treatment. Because of this delayed emergence of the new follicular wave, it is advised that the interval between estrogen treatment and induction of luteolysis be kept at 8–9 days (Fig. 7.4). Although estrogens can be effectively used for synchronization of the estrous cycle in dairy cows, their use in food-producing animals has been scrutinized, and many countries have banned the use of such products for reproductive management of dairy cattle.

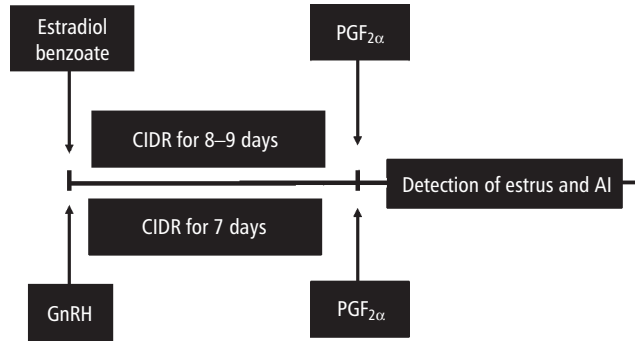

Figure 7.4. Methods to improve synchrony of estrus utilizing either GnRH/$PGF_{2\alpha}$ with supplemental progesterone for 7 days, or alternatively estradiol benzoate/$PGF_{2\alpha}$ with supplemental progesterone for 8–9 days.

Timed AI

Manipulation of the estrous cycle to improve service rate and fertility usually has a positive impact on PRs. Timed AI protocols rely on control of the estrous cycle by synchronizing follicular development, corpus luteum regression and, ultimately, ovulation to allow for insemination at fixed time with adequate P/AI (Thatcher et al., 2001). Such programs have become an integral part of reproductive management in many dairy herds (Caraviello et al., 2006) because of the recognized problems with expression and detection of estrus in dairy cows (Lucy, 2006).

The most accepted timed AI protocols in dairy herds in the United States are the Ovsynch and Co-Synch protocols, which consist of an injection of GnRH given at random stages of the estrous cycle, followed 7 days later by a luteolytic dose of $PGF_{2\alpha}$. For Ovsynch, a final GnRH injection is given at 48–56 h after $PGF_{2\alpha}$, and fixed-time AI is performed 12–16 h later as shown in Figure 7.5. When Co-Synch is utilized, cows are fixed-time inseminated 48 or 72 h after the $PGF_{2\alpha}$, and GnRH is given concurrently with AI. These protocols have been implemented very successfully in many commercial dairy farms as a strategy for AI during the first postpartum service, as well as for reinsemination of nonpregnant cows. Although timed AI protocols allow for insemina-

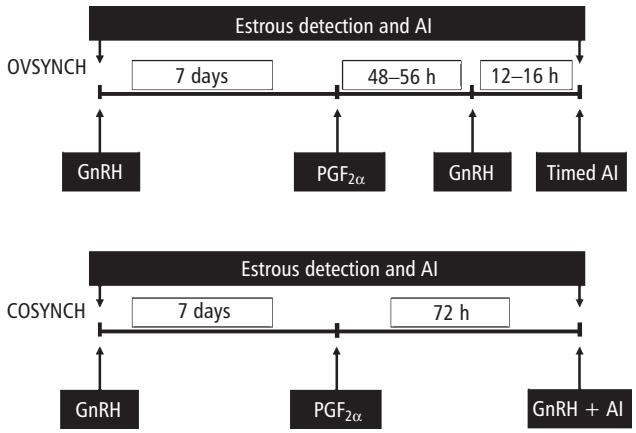

Figure 7.5. The Ovsynch and Co-Synch protocols for timed artificial insemination of dairy cows. Note that cows might display estrus during these programs, and detection of estrus is suggested for maximum pregnancy per insemination.

tion without the need for estrous detection, approximately 10%–15% of the cows display signs of estrus during the protocol. They should be inseminated promptly if maximum PR is to be achieved.

Pursley et al. (1997a) evaluated P/AI in lactating dairy cows ($n = 310$) and heifers ($n = 155$) when AI was performed following the Ovsynch protocol or a synchronization program utilizing only $PGF_{2\alpha}$ injections. Cows in the $PGF_{2\alpha}$ treatment received as many as three injections 14 days apart if signs of estrus had not been observed. Cows in this group not detected in estrus after the third injection of $PGF_{2\alpha}$ were timed-inseminated 72–80 h later. Pregnancies per AI for the two programs were similar, averaging 38%. For the lactating cows, estrous detection rate after the first two injections of $PGF_{2\alpha}$ averaged 54.0% following each injection, with an overall 81.8% for the 28-day period. Because of the low estrous detection rate in the $PGF_{2\alpha}$ group, cows enrolled in the Ovsynch-timed AI protocol experienced greater PR. In a subsequent study by the same group (Pursley et al., 1997b), lactating dairy cows from three commercial herds ($n = 333$) were randomly assigned to either the Ovsynch protocol or AI based on estrous detection with periodic use of $PGF_{2\alpha}$. Nonpregnant cows were reinseminated using the original treatment. Median days postpartum to first AI (54 vs. 83; $P < 0.001$) and days open (99 vs. 118: $P < 0.001$) were reduced in cows receiving Ovsynch compared with cows inseminated following detection of estrus.

The positive effects of timed AI, compared with reproductive programs based on detection of estrus, on reproductive efficiency of a herd are only observed when P/AI is not reduced with insemination at fixed time and detection of estrus is deficient (Tenhagen et al., 2004). When timed AI was implemented in two herds with distinctly different reproductive performance, the benefits from a systematic breeding program were more clearly demonstrated in the herd with poor estrous detection rate (Tenhagen et al., 2004).

Improving Response to Timed AI by Presynchronization

Response to the Ovsynch protocol is optimized when cows ovulate to the first GnRH injection of the program (Cerri et al., 2009b), and when a responsive CL is present at the moment of the $PGF_{2\alpha}$ treatment (Chebel et al., 2006). Vasconcelos et al. (1999) initiated the Ovsynch protocol at different stages of the estrous cycle and observed that synchronization rate to the second GnRH injection was higher when cows received the first GnRH injection prior to day 12 of the estrous cycle. Also, initiation of the Ovsynch protocol between days 5 and 9 of the estrous cycle resulted in the greatest ovulation rate. Ovulation to the first GnRH injection and initiation of a new follicular wave should improve P/AI (Chebel et al., 2006) because it results in a follicle with reduced dominance at AI (Cerri et al., 2009b). Furthermore, initiating the Ovsynch protocol prior to day 12 of the estrous cycle should minimize the number of cows that come into estrus and ovulate prior to the completion of the program (Moreira et al., 2001).

The importance of inducing follicle turnover was demonstrated when Cerri et al. (2009b) evaluated embryo quality in nonsuperovulated early lactation dairy cows. Cows receiving the Ovsynch protocol initiated on day 3 of the estrous cycle had lesser ovulation rate to the initial GnRH than those initiating the program on day 6 of the estrous cycle. The reduced ovulation rate (7.1% vs. 83%) was associated with smaller dominant follicles (9.5 vs. 14.8 mm) at the moment of the initial GnRH injection and extended period of ovulatory follicle dominance. When embryos were flushed on day 6 after AI, fertilization was similar among treatments, but cows initiating the Ovsynch on day 3 had embryos that were less developed and with fewer cells than those of cows initiating the Ovsynch on day 6.

Moreira et al. (2001) designed a presynchronization protocol to optimize response to the Ovsynch program by giving two injections of $PGF_{2\alpha}$ 14 days apart, with the second injection given 12 days prior to the first GnRH of the time AI protocol. This presynchronization program increased P/AI at 32 and 74 days after insemination in estrous cyclic cows. El-Zarkouny et al. (2004) later reinforced the findings of Moreira et al. (2001) and demonstrated an increased proportion of cows with high progesterone concentrations at initiation of

Ovsynch (59% vs. 72%) and improved P/AI (37.5% vs. 46.8%) regardless of cyclic status before initiation of the program. Because of the convenience of giving injections on the same day of the week, many producers have opted for administering the $PGF_{2\alpha}$ injections of the presynchronization protocol on the same day of the injections of the Ovsynch protocol, which results in an interval between presynchronization and initiation of Ovsynch of 14 days. Navanukraw et al. (2004) clearly demonstrated that a 14-day interval between presynchronization and initiation of the Ovsynch was beneficial to P/AI; however, in all these studies (Moreira et al., 2001; El-Zarkouny et al., 2004; Navanukraw et al., 2004), cows assigned to the control groups did not receive $PGF_{2\alpha}$ during the postpartum period, which might improve uterine health and, then, fertility of dairy cows. Furthermore, although presynchronizing cows 14 days before initiating the Ovsynch improved P/AI compared with no presynchronization (Navanukraw et al., 2004), the interval is not optimal and results in poor ovulation rate to the initial GnRH of the Ovsynch (Chebel et al., 2006; Galvão et al., 2007). Galvão et al. (2007) demonstrated that reducing the interval between presynchronization and timed AI from 14 to 11 days (Figure 7.6) increased ovulation to the initial GnRH of the timed AI protocol and improved P/AI.

Collectively, this data indicates that when timed AI is used in dairy herds, it is important to consider methods of presynchronization of the estrous cycle to optimize fertility of dairy cows. One such method is the sequential treatments with $PGF_{2\alpha}$ administered 14 days apart, and initiation of the timed AI 11 days after the second $PGF_{2\alpha}$ (Galvão et al., 2007).

Alternative Presynchronization Methods

Presynchronization with $PGF_{2\alpha}$ is only effective in estrous cyclic cows (Moreira et al., 2001). Because the prevalence of anovular cows is high in the first 60 days postpartum (Walsh et al., 2007; Santos et al., 2009), it is possible that methods that incorporate GnRH or progesterone might benefit cows prior to first AI. The use of CIDR during the presynchronization with $PGF_{2\alpha}$ was discussed previously, and no further benefit beyond what was obtained with $PGF_{2\alpha}$ alone was observed.

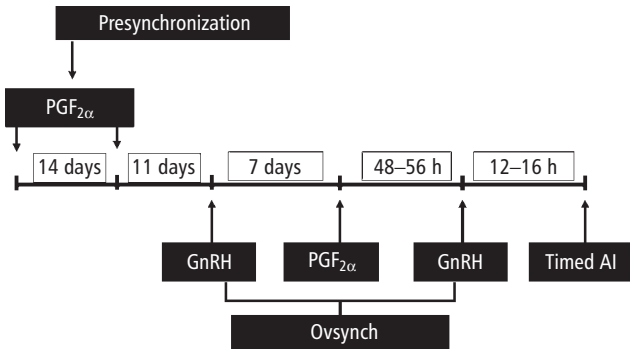

Figure 7.6. Diagram of treatments for presynchronization of the estrous cycle with $PGF_{2\alpha}$ followed by the Ovsynch protocol for first postpartum insemination of dairy cows.

Rutigliano et al. (2008) evaluated two presynchronization programs prior to the Ovsynch protocol for first AI. Cows received the two injections of $PGF_{2\alpha}$ 14 days apart, with the second injection given 12 days before the first GnRH of the Ovsynch protocol. The alternative presynchronization included CIDR for 7 days with an injection of $PGF_{2\alpha}$ at insert removal and initiation of the Ovsynch protocol 3 days later. Although the method of presynchronization altered ovulatory responses to the first GnRH of the Ovsynch and increased double ovulation, P/AI and pregnancy loss were similar between the two treatments. It is known now that initiating the timed AI program in proestrus, although beneficial to ovulatory response to the initial GnRH, can compromise fertility of dairy cows because of development of the ovulatory follicle under low systemic concentrations of progesterone (Bisinotto et al., 2010a), which compromises embryo quality (Rivera et al., 2011) and increases the risk of short luteal phases (Cerri et al., 2011a)

Table 7.3 is a summary of published literature in which the presynchronization program before the timed AI protocol was altered and fertility of dairy cows was measured by P/AI. The benefits to fertility were, generally, of small magnitude when compared with programs using $PGF_{2\alpha}$ alone. The use of $PGF_{2\alpha}$ followed by GnRH, with the beginning of the Ovsynch starting at 6 or 7 days later was not superior to the use of $PGF_{2\alpha}$ alone (Galvão et al., 2007; Ribeiro et al., 2009). In fact, even when $PGF_{2\alpha}$/GnRH combination for presynchronization was compared with no presynchronization at all, the benefit to fertility was limited (Peters & Pursley, 2002; Bello et al., 2006).

A potentially more promising system is the use of the double Ovsynch program; cows are subjected to two sequential Ovsynch protocols and insemination is performed at the end of the second program. Souza et al. (2008) observed that this strategy improved fertility of primiparous dairy cows when compared with presynchronization based on two doses of $PGF_{2\alpha}$. Ribeiro et al. (2011) compared similar strategy in 1754 lactating dairy cows in three herds subjected to grazing and supplemental concentrates. There were not overall differences in fertility between cows subjected to the double Ovsynch and cows presynchronized with two doses of $PGF_{2\alpha}$ as shown in Table 7.3. When the responses were divided according to cyclic status, those classified as cyclic (1495

Table 7.3. Effect of methods of presynchronization on P/AI following timed AI in dairy cows

	Method			
	Control	PGF	PGF-GnRH	Double Ovsynch
Bello et al. (2006)	27.0[d] (7/26)	—	50.0[c] (13/26)	—
Peters and Pursley (2002)	38.3 (80/209)	—	41.5 (90/218)	—
Galvão et al. (2007)	—	40.5 (166/410)	39.8 (156/392)	—
Ribeiro et al. (2009)	—	45.1 (285/632)	43.3 (269/622)	—
Ribeiro et al. (2011)	—	59.0 (514/871)	—	56.8 (501/882)
Souza et al. (2008)	—	41.7[b] (75/180)	—	49.7[a] (78/157)

[a,b] $P < 0.05$.
[c,d] $P < 0.10$.

cows) had P/AI of 60.1% and 63.2% when receiving the double Ovsynch and two doses of $PGF_{2\alpha}$ alone, respectively; for the 258 anovular cows, the P/AI were 38.2% and 34.7%, for double Ovsynch and two doses of $PGF_{2\alpha}$ alone, respectively.

Timing of Induction of Ovulation and Insemination in Timed AI Programs

Timing of induction of ovulation after luteolysis and subsequent interval to insemination in timed AI protocols influences fertility of dairy cows. Pursley et al. (1998) observed that P/AI were reduced when cows were inseminated 32 h after the GnRH injection, and maximum pregnancy and calving rates were observed when cows received timed AI at approximately 16 h after the final GnRH injection of the Ovsynch as shown in Figure 7.5. However, insemination of lactating dairy cows 16 h after the final GnRH requires management of cattle twice the same day, which often is seen as inconvenient and resisted by dairy producers. Because of such restriction, Portaluppi and Stevenson (2005) evaluated modifications of Ovsynch and observed increased pregnancy and calving rates, as well as reduced pregnancy loss when cows received the final GnRH and timed AI at 72 h after $PGF_{2\alpha}$ compared with cows that received the final GnRH 48 h after the $PGF_{2\alpha}$ and were inseminated either at 48 or 72 h. However, recent studies by others have not observed differences in P/AI when cows were subjected to the Co-Synch protocol either at 48 or 72 h (DeJarnette & Marshall, 2003; Sterry et al., 2007; Brusveen et al., 2008).

Work from Brusveen et al. (2008) demonstrated that maintaining an interval of 16 h between induction of ovulation with GnRH, when GnRH is given at 56 h after induction of luteolysis, and timed AI optimizes pregnancy per insemination in presynchronized cows at first AI and resynchronized cows as shown in Table 7.4. Therefore, it is advised that for lactating dairy cows, the Ovsynch program, in which GnRH is administered 16 h before AI, is a protocol preferable to inseminating cows concurrent with the final GnRH treatment as it occurs in the Co-Synch protocol.

Reducing the Period of Follicle Dominance in Timed AI Programs

The estrous cycle of lactating dairy cows is characterized by a greater incidence of two waves of follicle growth compared with those of growing heifers that are more likely to have three follicular waves (Savio et al., 1988). Cows with two waves of follicle development have the interval from follicle emergence to estrus of approximately 3.5 days longer than cows with three follicular waves (Bleach et al., 2004). It has been demonstrated that as the period of follicle dominance increases, embryo quality decreases (Cerri et al., 2009b) and fertility is compromised (Bleach et al., 2004). In fact, cows with three waves of follicle development had greater P/AI than those with two waves. Using the Ovsynch protocol, Cerri et al. (2009b) reported that ovulatory follicles with shorter length of dominance (5–6 days) yielded a greater proportion of better quality embryos than cows with ovulatory follicles with length of dominance greater than 6.5 days.

One means of reducing the period of ovulatory follicle dominance is to shorten the interval from follicle recruitment to luteal regression. The traditional timed AI programs based on GnRH/$PGF_{2\alpha}$ uses 7 days between the first injection of GnRH to the injection of $PGF_{2\alpha}$ to assure that a newly induced corpus luteum is responsive to the luteolytic effects of $PGF_{2\alpha}$. In these programs, more than 85% of the cows undergo luteolysis (Santos et al., 2010). However, in such programs, the period of

Table 7.4. Effect of timing of induction of ovulation and AI after induced luteolysis on pregnancy per AI of dairy cows

	Co-Synch[1]				
	48 h	60 h	72 h		
References	% (no. cows)			Ovsynch[2]	*P*
DeJarnette and Marshall (2003)	—	22.0 (173)	—	28.6 (175)	0.16
Portaluppi and Stevenson (2005)	22.8 (224)[b]	—	31.4 (220)[a]	23.5 (221)[b]	0.05
Hillegass et al. (2008)	44.0 (486)	—	44.7 (485)	—	0.27
Brusveen et al. (2008) presynchronized AI	38.0 (108)[a,b]	—	27.5 (120)[b]	45.2 (115)[a]	0.05
Brusveen et al. (2008) resynchronized AI	23.6 (386)[b]	—	27.2 (397)[a,b]	33.0 (342)[a]	0.05
Sterry et al. (2007) presynchronized AI	29.5 (146)	—	36.9 (206)	—	0.13
Sterry et al. (2007) resynchronized AI	28.0 (236)	—	29.7 (222)	—	0.93

[1] Cows received the final GnRH and timed AI either at 48, 60, or 72 h after induced luteolysis.
[2] Cows received the final GnRH either at 48 (Portaluppi & Stevenson, 2005) or 56 h (Brusveen et al., 2008) after induced luteolysis and timed AI was performed 72 h after induced luteolysis.
[a,b] Superscripts in the same row differ ($P < 0.05$).

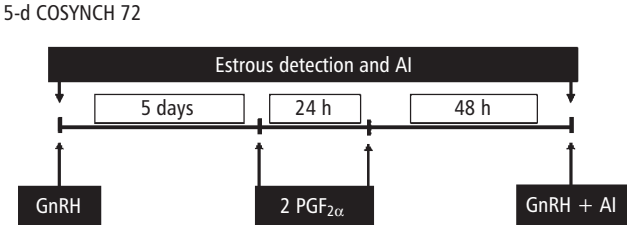

Figure 7.7. Diagram of treatments for the 5-day Co-Synch 72 h with two injections of $PGF_{2\alpha}$ administered 24 h apart.

follicle dominance in cows that do not ovulate to the first GnRH can be long, in some cases up to 10 days. Reducing the period of follicle dominance by decreasing the interval between the injection of GnRH to the injection of $PGF_{2\alpha}$ from 7 to 5 days increases P/AI in lactating dairy cows (Santos et al., 2010). In such program, an additional injection of $PGF_{2\alpha}$ is needed to assure that newly formed corpora lutea induced by the initial GnRH can be fully regressed (Fig. 7.7; Santos et al., 2010). Following presynchronization of the estrous cycle with two injections of $PGF_{2\alpha}$, cows were randomly assigned to a Co-Synch 72 h protocol (day 0 GnRH, day 7 $PGF_{2\alpha}$, day 10 GnRH + AI) or to a 5-day Co-Synch 72 h with two injections of $PGF_{2\alpha}$ (day 0 GnRH, days 5 and 6 $PGF_{2\alpha}$, day 8 GnRH + AI). Corpus luteum regression (96.3% vs. 91.5%) and P/AI (37.9% vs. 30.9%) were both greater for cows in the 5-day Co-Synch 72 h than the Co-Synch 72. When only cows that regressed their corpora lutea were evaluated, P/AI was still greater for the 5-day program (39.3% vs. 33.9%). Therefore, reducing the interval from GnRH to induced luteolysis to 5 days improves P/AI, but it requires two doses of doses of $PGF_{2\alpha}$ given 24 h apart to ensure complete regression of the corpus luteum.

Using a similar approach, Bisinotto et al. (2010b) conducted extensive experiments and demonstrated that for the 5-day program, P/AI was similar when cows received the final GnRH either 16 h before timed AI (day 0 GnRH, days 5 and 6 $PGF_{2\alpha}$, day 7.5 GnRH, day 8 AI) or concurrent with AI as previously described (46.4% vs. 45.5%). Recently, extensive studies with grazing dairy cows producing 7000 kg of milk/year have shown that the 5-day Co-Synch 72 h protocol resulted in P/AI ranging from 50% to 66% in over 3000 cows receiving the first insemination postpartum (Ribeiro et al., 2009, 2011). Thus, the 5-day Co-Synch 72 h program is an efficient synchronization program to optimize fertility of dairy cows.

Collectively, these programs that have fine-tuned the dynamics of follicle development, corpus luteum development and regression, and timing of ovulation and insemination assure that all cows are inseminated at a predetermined day and result in high P/AI.

Insemination After Presynchronization

A common program adopted on many farms in the United States is to administer two injections of $PGF_{2\alpha}$ at an interval of 14 days, with the second injection given at the end of the VWP. In many instances, the second $PGF_{2\alpha}$ injection is given at approximately 50–55 days postpartum. Cows are then inseminated following the second injection, and those not inseminated in the

following 11 days are enrolled in a timed AI protocol. Because 45%–55% of the cows display estrus and are inseminated following the second $PGF_{2\alpha}$ of the presynchronization, these cows end up receiving the first AI early in the postpartum period. Studies have demonstrated that P/AI of dairy cows improves as the lactation progresses up to 70–90 days postpartum (Pursley et al., 1997a; Tenhagen et al., 2003; Stevenson, 2006). Cows inseminated on estrus following the presynchronization have less P/AI than those inseminated after the completion of the entire program (presynchronized-timed AI), 3 weeks later (Bruno et al., 2005; Chebel et al., 2006). However, insemination of cows on estrus during presynchronization reduces the interval to first AI and costs associated with reproductive hormones and labor.

In an attempt to evaluate whether cows should be inseminated following presynchronization or subjected to timed AI, Chebel and Santos (2010) assigned 639 high-producing Holstein cows in early lactation to a short or long VWP by allowing or not insemination after the second $PGF_{2\alpha}$ of the presynchronization protocol. All cows received two injections of $PGF_{2\alpha}$ on days 35 and 49 postpartum. Cows assigned to the short VWP were inseminated if observed in estrus from 49 to 62 days postpartum, and those not inseminated were submitted to the Ovsynch-timed AI protocol, whereas cows assigned to the long VWP were all inseminated at 72 DIM following the Ovsynch protocol. The proportion of short VWP cows inseminated in estrus was 58.9%, and the interval from parturition to first AI was shorter for short VWP cows than for long VWP cows (64.7 ± 0.4 vs. 74.2 ± 0.5 DIM). Inseminating cows following the second $PGF_{2\alpha}$ of the presynchronization protocol did not affect P/AI after the first postpartum AI and the rate of pregnancy during the first 300 days postpartum. In some cases, inseminating cows following the second $PGF_{2\alpha}$ of the presynchronization results in less P/AI compared with cows that receive the presynchronization and are only inseminated at fixed time after the Ovsynch protocol (Bruno et al., 2005). However, despite the risk of a reduction in P/AI, cows inseminated following the presynchronization receive their first AI earlier, which compensates for the reduction in P/AI and results in similar interval to pregnancy (Chebel & Santos, 2010). The median days to pregnancy for cows in the short VWP that were allowed to be inseminated following the second $PGF_{2\alpha}$ of the presynchronization was 125, whereas in cows in the long VWP, in which all received timed AI, it was 134.5 days (Chebel & Santos, 2010).

These results suggest that insemination of cows after the second $PGF_{2\alpha}$ of the presynchronization results in similar or slightly less P/AI, but because cows are inseminated earlier, the interval postpartum to pregnancy is not altered. This gives flexibility to producers who might decide to inseminate cows that display estrus after the second $PGF_{2\alpha}$ of the presynchronization, or inseminate all cows at timed AI. The first option reduces costs with treatments, but the latter optimizes first service P/AI, with both resulting in similar time to pregnancy. Of course, estrous detection efficiency of the herd would be an important factor for success of the estrous detection-based program (Tenhagen et al., 2004).

Use of Progesterone Inserts with Ovulation Synchronization Protocols

Progesterone inserts such as the CIDR are capable of delivering sufficient progesterone to block luteolysis and to induce estrous cyclicity in anovular cows (Chebel et al., 2006; Cerri et al., 2009a). Therefore, they become attractive tools to be used in reproductive programs to tighten the synchrony of estrus and ovulation and to improve fertility of anovular dairy cows or cows with low concentrations of progesterone. When cows have their estrous cycle presynchronized with $PGF_{2\alpha}$ and they all receive timed AI, incorporation of the CIDR into the program is usually not beneficial to fertility (El-Zarkouny et al., 2004; Galvão et al., 2004). On the other hand, supplemental progesterone during the timed AI is beneficial to fertility when cows are either not presynchronized (El-Zarkouny et al., 2004; Stevenson et al., 2006) or, if presynchronized, inseminated in estrus after the second injection of $PGF_{2\alpha}$ of the presychronization (Melendez et al., 2006; Chebel et al., 2010). The benefits of supplemental progesterone seem to occur despite the estrous cyclicity in dairy cows. Both estrous cyclic and anovular cows had similar improvements in fertility when progesterone was supplemented during the Ovsynch protocol (Stevenson et al., 2006; Chebel et al., 2010). The benefit to fertility is thought to be mediated, to a great extent, by improving synchronization of the estrous cycle following the timed AI (Lima et al., 2009; Chebel et al., 2010). Therefore, when producers opt to use timed AI programs without previous presynchronization of the estrous cycle, it is beneficial to incorporate a CIDR during the program to improve synchrony of ovulation and optimize fertility. Similarly, when presynchronization is used, but cows observed in estrus are inseminated before reaching the timed AI program, use of the CIDR in the remaining cows seems beneficial to fertility.

Summary

Implementation of systematic breeding programs for first postpartum insemination in dairy herds has become an integral part of the reproductive management of dairy cows. These programs have allowed for increased

insemination rates without compromising fertility. It is known that the first 3 weeks past the end of the VWP is the estrous cycle of greatest impact on the reproduction of the dairy herd. Therefore, assuring high PR in those days is critical to optimize reproduction of dairy cows.

The development of synchronization protocols that follow physiological principles is critical to optimize fertility, but these programs should be tailored to the needs and ability of the farm to implement them. In herds with excellent 21-day estrous detection rate (>65%), it is unlikely that aggressive synchronization programs will have a major impact on the reproductive performance of the herd. On the other hand, because of the low estrous detection efficiency in most farms, the use of estrous or ovulation synchronization protocols is often attractive and benefit reproduction.

It is important to emphasize that in order for systematic breeding programs to work and benefit the economy of the dairy farm, there must be high compliance at every step of the program. Each individual farm has to develop a system to assure that cows receive the correct hormonal treatment on the correct day. Failure to comply with the programs results in reduced insemination rate and fertility. Because some programs require handling of cows multiple times to administer hormonal treatments, it is important that they are tailored to the needs of the farm, as long as critical steps are not ignored.

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8

Applications of Ultrasonography in Dairy Cattle Reproductive Management

Jill D. Colloton

Abstract

Ultrasound has been used for reproductive examinations in cattle since the early 1980s and has advanced considerably since then. In this chapter we discuss the uses of ultrasound for reproductive examinations and the advantages over rectal palpation. Early pregnancy diagnosis, fetal gender determination, gestational aging, twinning, determination of fetal viability, diagnosis of ovarian structures, and diagnosis of uterine pathology are discussed in detail. The use of ultrasound as a companion technology to synchronization protocols and embryo transfer is also considered.

Introduction

In 1986, Dr. O.J. Ginther, the most prominent pioneer of bovine ultrasound, said, "Gray-scale, real time ultrasonography is the most profound technological advance in the field of animal research and clinical reproduction since the introduction of transrectal palpation and radioimmunoassay of circulating hormones" (Ginther, 1995). In the early 1980s, ultrasound had already begun to replace manual palpation as the diagnostic tool of choice for equine reproductive examinations. The use of ultrasound for routine reproductive examinations in the bovine lagged behind due to the large size and high cost of ultrasound machines. Today, however, machines are remarkably portable and reasonably priced. There is no longer any excuse for bovine veterinarians or researchers not to avail themselves of the benefits of this technology. This chapter will review the reasons for and the methods of bovine reproductive ultrasound for early pregnancy diagnosis, later pregnancy evaluation and gestational aging, twinning, embryonic and fetal viability, uterine health, ovarian structures, staging the estrous cycle, synchronization protocols, and embryo transfer.

Ultrasound Physics and Terminology

Diagnostic ultrasound is most simply described as inaudible sound waves penetrating or being reflected by tissues of varying densities. Piezoelectric crystals housed in a transducer convert electrical energy from the machine's power source into ultrasound waves. When these waves strike tissue they may pass through, be scattered, or be reflected back to the transducer. Waves that are reflected back to the transducer re-excite the piezoelectric crystals which convert the sound wave energy back to electrical energy which in turn is read as pixels on a monitor. Very dense tissues, such as bone, fibrous tissue, or the genital tubercle, reflect most of the waves and are thus seen on the monitor as very white. These structures are hyperechoic or highly echogenic. Conversely, fluid allows most of the waves to pass through, appearing as black on the monitor. Examples include follicular fluid, the fluid of early pregnancy, and blood. Fluid is nonechogenic or anechoic. Tissues with densities in between bone and fluid appear on the monitor in various shades of gray.

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Most bovine ultrasound units are equipped with a linear rectal transducer. Such transducers have up to 126 crystals aligned in a linear array across the face. These crystals fire in rapid succession, producing a rectangular image. Sector or curvilinear transducers are less commonly used for bovine examinations. Frequency of the crystals in most bovine reproductive units ranges from 5 to 9 MHz, with 5 MHz being the most common. Lower frequencies allow deeper penetration of tissue, but provide less resolution, and vice versa. Many newer units have variable frequency probes that adjust frequency depending on the depth of the tissue being scanned.

The two-dimensional image on the monitor screen represents an approximately 2 mm "slice" of the tissues being scanned. Thus, a still frame ultrasound image is similar to a histopathological section. It represents only a small portion of the organ or tissue being examined. Hence, a thorough ultrasound examination is dynamic. The ultrasonographer must move the transducer across the entire area of interest in order to avoid missing important structures.

It behooves novice ultrasonographers to remember that ultrasound images look exactly like a black and white section through the organ or tissue being examined. Figure 8.1 shows a cross-section through mid-abdomen of a male fetus at approximately 85 days. Note the easily differentiated fetal stomach, liver, intestines, penis, and amniotic membrane. Ultrasonography is a learned skill, but it is not "rocket science." Any veterinarian or animal scientist with good technical skills and a sound knowledge of anatomy and physiology can become an excellent ultrasonographer.

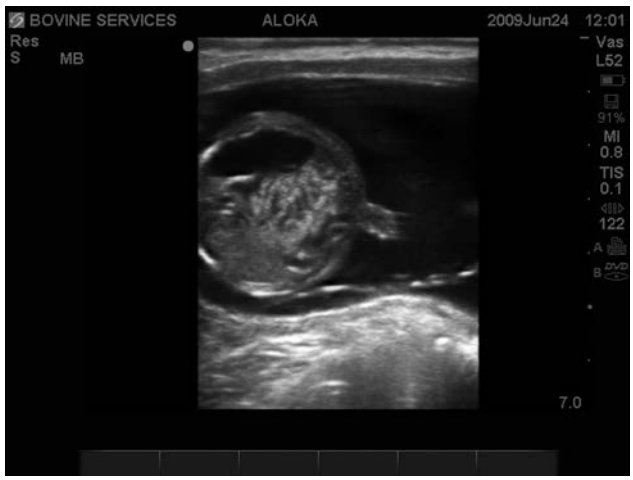


Figure 8.1. Cross-sectional scan through mid-abdomen of a male fetus. Note the black viscus representing the fetal stomach, the homogeneous gray tissue representing the liver, and the heterogeneous mass between representing intestines. The genital tubercle projects from the abdomen at 3:00.

For a much more thorough discussion of ultrasound basics refer to Dr. O.J. Ginthter's excellent *Ultrasonic Imaging and Animal Reproduction: Fundamentals* (Ginther, 1995).

Early Pregnancy/Open Diagnosis

Any initial examination for pregnancy status is for the purpose of finding open cows. The sooner these cows can be resubmitted to the breeding pool, the fewer days open they will experience, resulting in higher profit for the dairyman. In a 2004 survey from Cornell University, the median days since breeding that responding veterinarians using palpation were confident enough of their palpation skills to administer prostaglandin to open cows were 35 days. For veterinarians using ultrasound, it was 28 days (Rosenbaum & Warnick, 2004).

Under research conditions, the embryonic vesicle in dairy heifers has been identified as early as 11 days and the embryo proper as early as 20 days (Ginther, 1998). However, in field conditions, the risk of misdiagnosing either open or pregnant cows this early is significant. One study (Romano et al., 2006) suggests that sensitivity (cows correctly identified as pregnant) of ultrasound for pregnancy diagnosis can reach 100% at 29 days in adult cows and 26 days in heifers in the hands of a skilled operator. Specificity (cows correctly identified as open) is more difficult to measure because a certain level of embryonic loss is normal in the early stages of pregnancy.

Several things must be considered when deciding when to begin pregnancy/open examinations. First, every ultrasonographer must determine his or her own skill level. This author, after 14 years of scanning cows, remains extremely cautious of making a diagnosis of open prior to day 27 in adult cows and day 26 in heifers. The risk of incorrectly diagnosing a pregnant cow as open must be avoided at all costs. Second, it is not useful to clients if an examination does not permit an immediate management decision. Examinations performed so early that a second examination is required before suggesting treatment are uneconomical both in money and the use of time. Third, timing of synchronization protocols affects when pregnant/open examinations are best done (see "Ultrasound with Synchronization Protocols" later in this chapter). Finally, frequency of herd visits can affect how early examination must be done. Less frequent (monthly) herd visits necessitate earlier pregnant/open examinations than do more frequent visits (weekly) in order to avoid excessive days open.

It is extremely helpful to scan both ovaries during any pregnancy/open examination. The presence or absence of a corpus luteum (CL), the location of the CL, and the

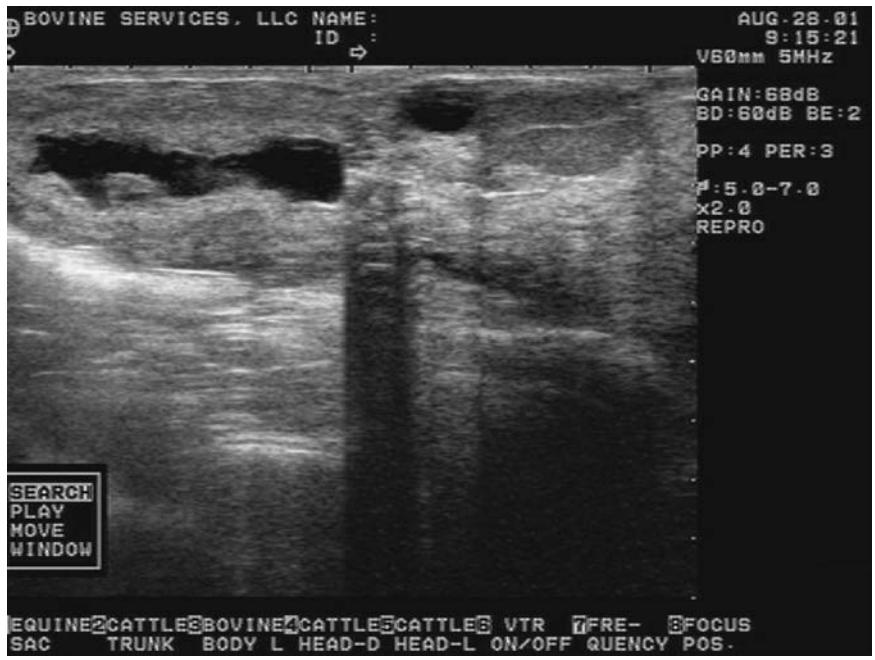


Figure 8.2. Twenty-eight-day pregnancy. The fetus on the left side of the image is about 1 cm in length. The fluids of pregnancy are clear, appearing black on the monitor. The right side of the image shows a mature CL with a small follicle.

number of CLs provide clues to the potential for pregnancy, the location of the conceptus, and the potential for twins. Furthermore, for cows diagnosed open, the ovarian structures will help determine stage of cycle or presence of pathology. See later sections on ovarian diagnosis, twinning, staging the estrous cycle, and synchronization in this chapter.

In the early stages of pregnancym the uterine fluids will be clear and nonechogenic, thus appearing black on the monitor, as seen in Figure 8.2 showing a 28-day pregnancy. It may be difficult to identify the embryo itself prior to day 27, particularly if it is located adjacent to the uterine wall. By day 30 the embryo is easily located. Because the embryonic heart develops early and occupies a large portion of the embryo, the heartbeat is usually readily visualized as early as 24 days if the embryo can be located. The embryonic heart rate should be over 130 bpm, appearing almost as a vibration on the monitor.

Until about day 35, most of the visible fluids of pregnancy will be in the gravid horn. After 35 days the chorioallantoic fluids can usually be seen in both uterine horns. By this time the amnion can often be visualized as a thin line around the embryo. In the 38-day pregnancy shown in Figure 8.3 the head, limb buds, and placentomes can be identified. By day 55, development of the limbs, skeletal structures, and organs has progressed to the point that the fetus resembles a tiny version of the fully formed calf it will become (Curran, 1986). See Figure 8.4.

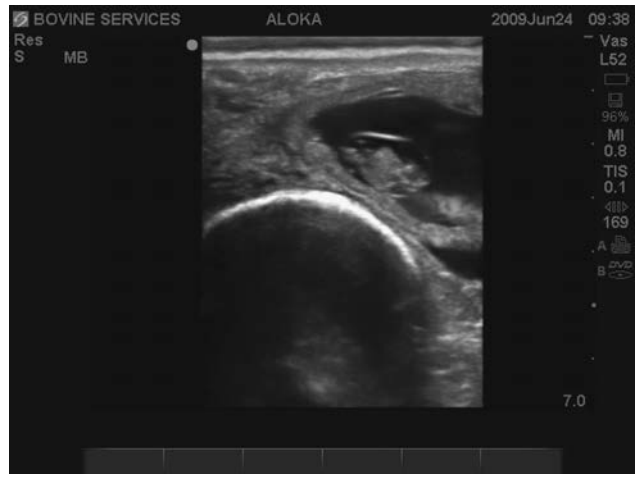


Figure 8.3. Thirty-eight-day pregnancy. The thin white line surrounding the fetus represents the amniotic vesicle.

Later Pregnancy Evaluation and Fetal Gender Determination

Due to the reality of embryonic and fetal loss in dairy cattle, it is important to perform a second examination after the embryonic/fetal loss curve drops off at about 60 days. This is an easy time to confirm fetal viability, identify twins, and determine the gender of the fetus. In the hands of an experienced ultrasonographer, fetal gender determination is quick (on average less than 1 min) and provides important information to the client.

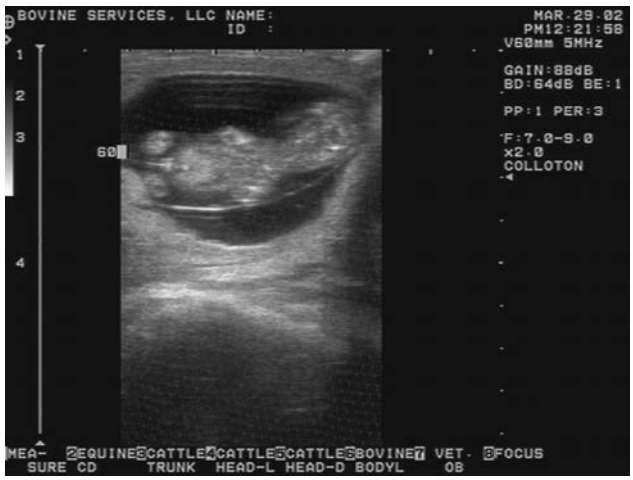


Figure 8.4. Sixty-day male fetus. The future shape of the fetus is well-defined at this stage. Note the head to the right, cross sections of all four limbs, and the male genital tubercle in this longitudinal view.

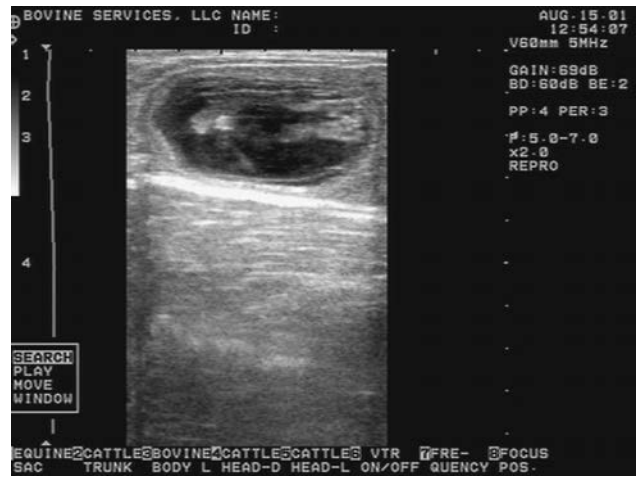


Figure 8.5. Seventy-day female fetus. This cross-sectional view through the most posterior aspect of the fetus shows cloven hooves, tarsi, and the perineal area with the mono-lobed tail head and the bilobed female genital tubercle.

For commercial dairies, the most important use for this information is for cull decisions. Marginal or problem cows carrying females may merit more investment than those carrying males. Alternatively, cows carrying females can be sold for a premium if overcrowding allows elective culling. Other uses of this information include management of calving pens, planning for herd inventory, and evaluation of gender-selected semen. Registered breeders want to know fetal gender when they have bull contracts on a mating. If no male fetuses are found, they still have time to produce more embryos from the mating before the sire is obsolete.

Fetal gender determination can be accurately done as early as 55 days and until the fetus is beyond reach of the ultrasonographer, sometimes as late as 130 days. The optimal time for many ultrasonographers is 60–80 days, when nearly 100% accuracy can be achieved (Curran, 1992). At this time, the genital tubercle is very visible and completely migrated to its final position. Also, the fetus is still within reach and small enough to orient under the transducer.

The genital tubercle will become the penis in the male and the clitoris in the female. Hence, it is located behind the umbilicus and cranial to the thighs in the male as shown in Figure 8.4 and under the tail head and caudal to the thighs in the female as shown in Figure 8.5. In both genders it usually appears as a hyperechoic bilobed structure, although it sometimes appears to have one or three lobes. Teats and scrotum may also be visualized, but it is inadvisable to use these soft tissue structures alone for the diagnosis of fetal gender. Excellent training tools for gender determination techniques include DVDs by Brad Stroud (Stroud, 1996a,b) and O.J. Ginther (Ginther, 1995).

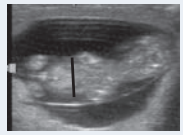
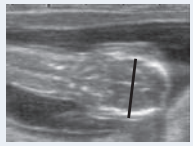
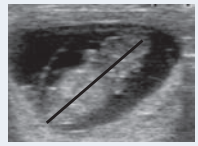
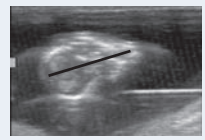
Gestational Aging

Ultrasound is more accurate for gestational aging than palpation because it measures the fetus itself, not just the amniotic sac or fluid of pregnancy. Embryonic and early fetal growth is very consistent. The amount of pregnancy fluid, however, varies among individuals and with ambient temperatures. Most ultrasound monitors have a grid or hash marks in one centimeter increments that can be used to measure size. Many also have calipers that can be used for more accurate estimations of embryonic and fetal size. Some even have software that can calculate the estimated conception or due date based on fetal measurements.

Crown-rump length is the full length of the embryo or fetus from tail head to crown of the skull. It can be used to estimate age until the fetus begins to curve at about 50 days. An easy and accurate formula for early fetuses is: length of the fetus in millimeters (mm) + 18 = fetal age in days. Several measurements can be used to age older fetuses. The calculations for these measurements are not linear so a fetal aging chart shown in Table 8.1 must be used (White et al., 1985; Kahn, 1989). Braincase diameter is measured just caudal to the eyes at the maximum diameter of the skull. Trunk width is measured in a frontal plane at the widest part of the ribcage, just cranial to the abdomen.

As with palpation, estimates of fetal age after 120 days are difficult. The fetus is often inaccessible, and varia-

Table 8.1. Fetal aging chart, adapted from White et al. (1985) and Kahn (1989)

Trunk diameter	Days	Braincase diameter	Days	Crown/rump length	Days	Head length	Days
15	54	7	50	4	20	25	62
20	65	11	55	6	25	30	70
25	73	15	62	9	28	35	76
30	80	20	69	10	35	40	82
35	86	23	75	15	37	45	86
40	91	25	79	20	40	50	90
45	95	28	85	25	42	55	94
50	99	30	87	30	45	60	98
55	103	31	90	35	48	70	104
60	106	35	94	40	50	80	109
70	112	40	100	45	52	90	114
80	117	45	105	50	54	100	118
90	121	50	110	60	57	110	122
100	125	60	118	70	60	120	126
110	128	70	125	80	62	130	129
120	132	80	131			140	132

tions in fetal size become more pronounced. Placentomes or the uterine arteries have been proposed as fetal aging tools in later gestation, but there is a very wide variation in size of both among cows.

Twinning

Twinning rates are increasing in dairy cattle. In one retrospective study, twinning rates increased from 1.4% in lactating dairy cattle in 1983 to 2.4% in 1993 (Kinsel et al., 1998). Peak milk production was the greatest risk factor for twinning in this study. It is not unusual for individual herds to have considerably higher twinning rates. Twinning is a problem in the dairy industry because it can lead to more pregnancy loss, more stillbirths, more periparturient disease, and reduced future reproductive performance (Van Saun, 2001).

In spite of this, it is not generally recommended to abort twins for two reasons. First, it is difficult to get lactating cows pregnant, and terminating a pregnancy can lead to very excessive days open. Second, cows that conceive twins tend to double ovulate in subsequent cycles, leading to the risk of conceiving twins again. One possible exception might be heifers carrying twins, particularly if they are young enough to rebreed in a timely fashion.

Cows known to be carrying twins can be managed more carefully before and during parturition to reduce the magnitude of problems. First, it is especially critical that these cows receive a second pregnancy confirmation after 60 days, and perhaps another confirmation prior to dry-off due to higher risk of pregnancy loss throughout gestation. Attention to body condition score is particularly important because the large mass of late gestation twins reduces feed intake. Cows carrying twins also tend to calve about 2 weeks early. Hence, some experts recommend early dry-off to allow the standard recommendation of 60 days dry. Others recommend not adjusting the dry-off date, believing that these cows benefit from a higher density lactating ration even at the expense of a shortened dry period. Obviously, extra attention is merited at calving time to avoid dystocia and maximize the chance of both calves surviving.

Manual palpation is inadequate for the diagnosis of twins. In one study in which a concerted effort was made to identify twins by manual palpation, only 64% of twins were identified (Callahan & Horstman, 1990). In another study, only 49.3% of twins were identified by palpation

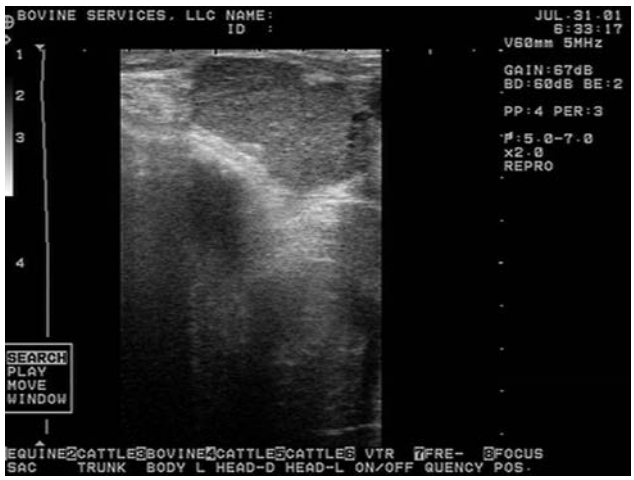


Figure 8.6. Two corpora lutea on the same ovary. Pregnant animals with multiple corpora lutea should be carefully examined for twins.

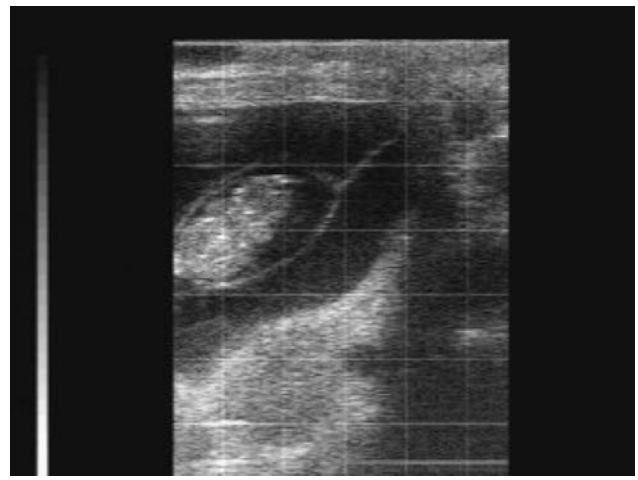


Figure 8.7. Twin line. The thin line projecting away from the fetus at 2:00 suggests the presence of a second fetus.

(Day et al., 1990). This is likely worse in normal field conditions when the practitioner is pressed for time.

Ultrasound examination for twins can not only improve the accuracy of diagnosis but can also assess the viability and potential for loss of these high-risk pregnancies. Embryonic and fetal loss of twins is higher than for singles throughout pregnancy, particularly for twins in the same uterine horn. In one study, from first examination at between 36 and 42 days to recheck examination at 90 days, only 8% of bilateral twins were lost, whereas for unilateral twins, 32% were lost (Lopez-Gatius & Hunter, 2005). Interestingly, cows may also experience reduction from twins to a single fetus. This rate was 6.2% in the previous study and 11.2% in another study (Silva-del-Rio et al., 2006).

Twin diagnosis should begin with a complete examination of both ovaries. Only 4.7% of twins are monozygous (Silva-del-Rio et al., 2006) so cows with multiple CLs should receive a more careful examination of the uterus for twins. Approximately 50% of pregnant cows with two CLs will have twins (Silva-del-Rio et al., 2009). Location of the CLs also helps determine whether the twins are unilateral or bilateral, an important distinction in evaluating risk of pregnancy loss. The two CLs on the same ovary in Figure 8.6 would alert the practitioner to the possibility of unilateral twins. In pregnancies less than 32 days, it may be time-consuming to confirm the presence or absence of twins. To expedite early examinations, a note can be made if multiple CLs are present and the final twin evaluation can be made more quickly at the recheck examination.

Twin pregnancies tend to have more fluid and more fetal membranes than single pregnancies. Sometimes a twin line will be seen, as in Figure 8.7, especially in twins less than 60 days. This line represents the shared chorioallantoic membrane between the two fetuses, clearly seen in Figure 8.8. It is distinguished from the amnion because it moves away from the fetus rather than being a circle around the fetus. After 60 days the amniotic and chorioallantoic membranes elongate and fold, confusing evaluation of the twin line. Obviously, the only cardinal sign of twins is finding two fetuses. Because of the high loss rates for twins, it is especially important to assess fetal viability of both fetuses. See the next section for further discussion of fetal viability.

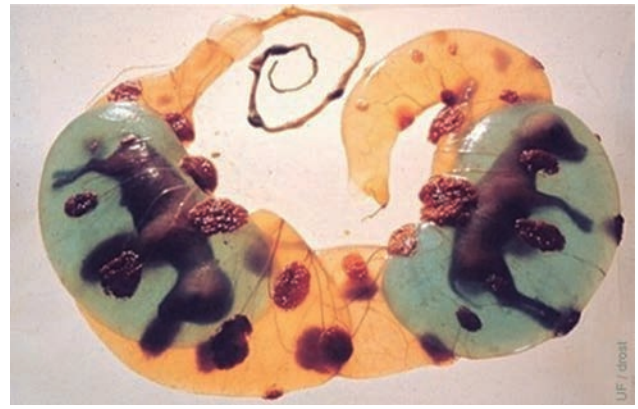


Figure 8.8. Junction of the chorioallantoic membranes of twin fetuses. Photo courtesy of the Drost Project.

Embryonic and Fetal Viability

Embryonic (up to day 42) and early fetal (up to day 56) death rates are high in lactating dairy cows, with the

highest loss rates earlier in pregnancy. Vasconcelos et al. reported an 11% pregnancy loss from day 28 to day 42, 6.3% loss from day 42 to day 56, and 9% loss for the remainder of gestation (Vasconcelos et al., 1997). Loss rates vary with ambient temperature and herd management, but the shape of the loss curve remains the same. This author rarely sees loss rates this high in healthy, well-managed herds in the absence of heat stress, with most such herds having loss rates of 6%–8% from day 30 to day 60. Regardless of pregnancy examination method used, any pregnancy diagnosis prior to 50 days should be followed by a recheck examination after 60 days. It is critical that the ultrasonographer explains this loss curve to clients. They must understand that the earlier an examination is done, the more important a recheck examination becomes. Clients should also understand that some level of embryonic and fetal loss is natural and is not caused by the examination. Early pregnancy loss, however, should not discourage early pregnancy/open examinations. These early examinations are critical for returning open cows to the breeding pool sooner.

In many cases of embryonic and fetal death, the conceptus remains in the uterus for an extended period of time. Kastelic and Ginther followed fetal death after injection of colchicine at day 42 and found that discharge of the conceptus occurred on average 2 weeks after death (Kastelic & Ginther, 1989). The same scenario occurs in natural embryonic or fetal death when the CL fails to regress. Manual palpation of these cases reveals fluid, a membrane slip, and often an intact amniotic vesicle or fetus. Hence, without ultrasound, much time is lost before the cow is diagnosed as open and returned to the breeding pool.

Ultrasound can readily identify cases of embryonic/fetal death and sometimes even embryonic/fetal distress. Signs of embryonic and early fetal deaths up to day 56 include one or more of the following: lack of heartbeat, separation of the chorioallantoic membrane, greater heterogeneity of the fetus with more hyperechoic areas, and floccular pregnancy fluids, as shown in Figure 8.9. It is inadvisable to diagnose fetal death on the lack of heartbeat alone, as the heartbeat can be difficult to visualize if the cow is moving.

After day 56, separation of the chorioallantoic membrane is difficult to identify because all the placental membranes are beginning to elongate and fold. Also, the fluids of pregnancy in later stages may naturally become flocculent. However, at this stage, lack of fetal movement and heartbeat, as well as obvious degradation of the fetus are easily identified in cases of fetal death. In either case, the practitioner should fully examine both uterine horns, keeping in mind that it is possible to have a dead twin accompanied by its live partner (Lopez-Gatius & Hunter, 2005; Silva-del-Rio et al., 2009). When a dead embryo/fetus is confirmed, the use of prostaglandins will usually cause expulsion within 2 days, allowing the cow to be bred back at the next natural or synchronized heat.

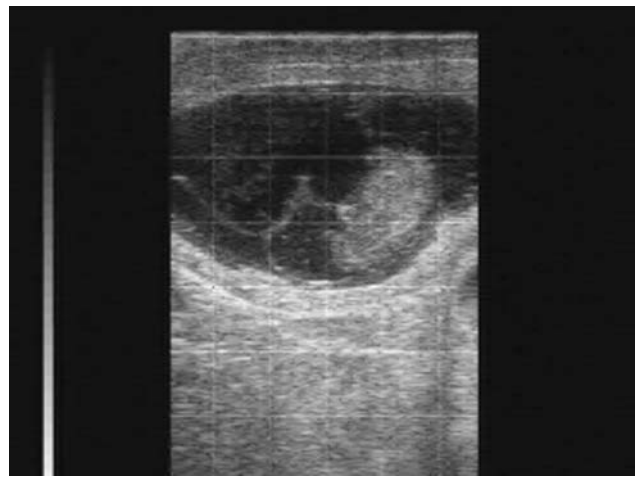


Figure 8.9. Floccular fluids of pregnancy, separation of the placental membranes, and lack of form of the fetus indicate fetal death.

Embryonic and fetal distress may be accompanied by a slow (less than 130 bpm) heart rate, separation of the chorioallantoic membranes or flocculent pregnancy fluids in the presence of a live embryo or fetus, less fluid than expected for stage of gestation, a smaller embryo or fetus than expected for stage of gestation, or fetal anomalies. A poor quality CL, a CL contralateral to the gravid horn, and twins (particularly in the same horn) are also indicative of high-risk pregnancies. In these cases, a recheck examination is warranted at the next farm visit.

Uterus

Ultrasound examinations of the nongravid uterus can be used to help evaluate stage of the estrous cycle and diagnose pathology. The normal diestrus uterus is relatively homogeneous in echotexture and usually has no visible fluid in the lumen. In proestrus and estrus the uterus becomes more heterogeneous due to dilation of blood vessels and edema. Also, hypoechoic fluid begins to accumulate in the lumen approximately 3 days before ovulation. Bright white horizontal lines are often seen at the interface of the uterine lumen and endometrial wall at this time. These are specular reflections that commonly occur when two interfaces of very different densities are aligned horizontally to one another and perpendicular to the ultrasound beam. Figure 8.10 shows the classic appearance of a uterus and ovary during estrus. Shortly after estrus, the fluid in the lumen disappears, and the

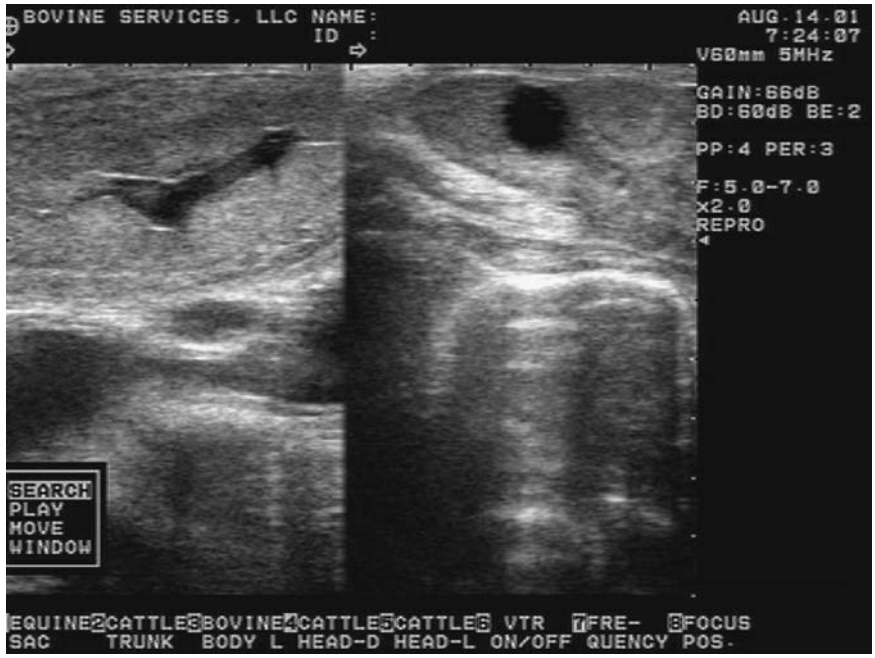


Figure 8.10. Estrous uterus and accompanying ovary with follicle. Clear fluid, specular reflections, and heterogeneity of uterine wall on the left side of the image are indicative of estrus. There is an 18-mm follicle on the right side of the image, accompanied by a regressing CL.

heterogeneity of the uterine wall decreases as progesterone levels increase, returning to baseline by about day 2 of the cycle (Adams, 2005).

Detection of uterine pathology is much easier with ultrasound than with palpation. Ultrasound can detect much smaller volumes of fluid (down to 2 mm) and can also determine the character of the fluid (clear, cloudy, or dense). In metritis or pyometra, the uterine content may vary from slightly to highly echogenic, depending on the density of the purulent material. Sometimes the fluid can be seen to move, especially if the uterus is balloted. Contrast the appearance of the normal hypoechoic fluid of estrus in Figure 8.10 with the cloudy fluid of metritis in Figure 8.11. Both cows were in estrus, but the cow in Figure 8.11 clearly would not be fertile. Palpation alone would not be sufficient to evaluate the character of the fluid in these animals.

Mucometra is far less common than pyometra and metritis, but represents a serious reproductive challenge. The fluid of mucometra is usually more excessive than estrus fluid and does not disappear in diestrus. It can appear completely nonechogenic, but sometimes has a "sparkly" appearance due to small echogenic particles. Mucometra may accompany cystic ovarian disease, but can also be seen in normally cycling cows. In heifers, mucometra may indicate segmental dysplasia of the uterus. Great care must be taken to differentiate mucometra from pregnancy. Obviously, in mucometra, no placental membranes, placentomes or fetus will be visualized.

Uterine abscesses or tumors can also be identified and differentiated with ultrasound. Abscesses have thick echogenic walls and contain purulent material of varying echogenicity depending on density. Lymphosarcoma is the most common uterine neoplasia in cattle. The affected area is very hyperechoic and firm. By palpation, lymphosarcoma might be mistaken for a mummified fetus due to the firmness of the tissue, but on ultrasound examination, it is clear that the uterine wall rather than its contents is affected. Enlarged pelvic lymph nodes are also often visualized in lymphosarcoma cases. For less common neoplasias, ultrasound can be used to locate and determine the extent of tissue affected. It can also be used to perform a needle-guided biopsy for laboratory evaluation.

Cervix, Vagina, and Oviducts

Although not always examined during routine reproductive examinations, the cervix, vagina, and oviducts can be scanned when pathology is expected. The normal cervix appears in longitudinal section as a series of relatively echogenic columns representing the cervical rings. In cross section, each cervical ring looks somewhat like a donut, having a thick echogenic wall and a small nonechogenic center representing the cervical lumen. In cer-

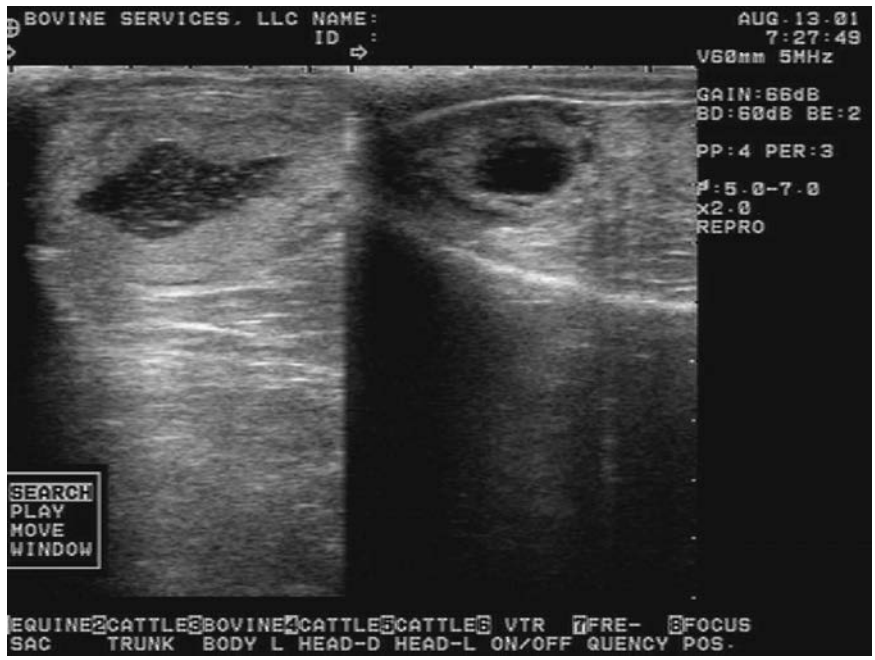


Figure 8.11. Metritis and accompanying ovary with follicle. The cloudy fluid in the uterine lumen indicates metritis.

vicitis the cervical walls are thickened and echogenic purulent material may be seen in the lumen.

The normal vagina appears as a thin white line representing the confluence of its walls. In cases of vaginitis, purulent material appears within the lumen in varying shades of gray. Urine pooling generally has less echogenicity in the fluid, although there may be flocculent material due to cystitis or accompanying vaginitis. Pneumovagina is seen as half-moon-shaped, sequential, bright white lines vertically aligned on the monitor. These are reverberation artifacts which occur any time an ultrasound beam reaches a gas interface.

Normal oviducts are usually not seen on a routine scan. Salpingitis or blockage may cause them to be large enough to be visible.

Ovary

Ultrasound has led to enormous improvements of our understanding of ovarian structures and dynamics in cattle, beginning in 1984 when the first observations of follicular wave patterns were made (Pierson & Ginther, 1984). It is not within the scope of this section to review all of the vast research in this area. Instead, a practical summary will be provided to assist the practitioner in using ultrasound to more accurately assess ovarian status and pathology.

CL

The CL is perhaps the most important ovarian structure for identifying the reproductive status of the cow. Absence of a CL on repeated examinations indicates the animal is anovular. When present, the character of the CL can assist in estimating the stage of the estrous cycle (see the following section in this chapter). Ultrasound is a highly sensitive method for detecting the presence of a CL. In one early study, ultrasound examination agreed with dissection 96.9% of the time when a proficient operator used a high-quality machine (Lean et al., 1992).

With a good field ultrasound unit, the presence of a CL can be identified as early as 2 days postovulation, and even earlier with a research-quality machine. Metestrus CLs are more heterogeneous and smaller than diestrus CLs or those of pregnant cows (Singh et al., 1998). Up to 80% of CLs have a fluid cavity at some time in their development, usually early (Kastelic et al., 1990). These structures can be confused with follicles or follicular cysts by rectal palpation, but are easily identified by ultrasound due to their thicker wall. Figure 8.12 and Figure 8.13 show young and mature cavitary CLs, respectively. The differentiation of cavitary CLs and cystic CLs is perhaps a matter of academic semantics. This author prefers not to use the term cystic CL unless the structure is proven by repeated examinations to be persistent beyond the normal life of a CL. In either case, luteal structures are responsive to prostaglandins and synchronization protocols.

The classic mature (diestrus or pregnancy) CL is about 2.5–4 cm at the widest plane and has a homogeneous grainy appearance and is shown in Figure 8.6. Usually, any cavity has filled in with luteal tissue by this stage, but not always. Sometimes, the cavity even persists

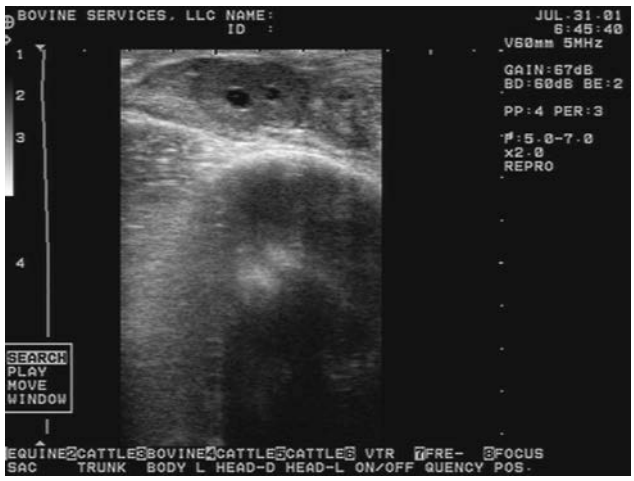


Figure 8.12. Two typical 7-day CLs on the same ovary. The small size (about 14 mm) and central cavities of these CLs are typical 7 days postestrus, although variations are common.

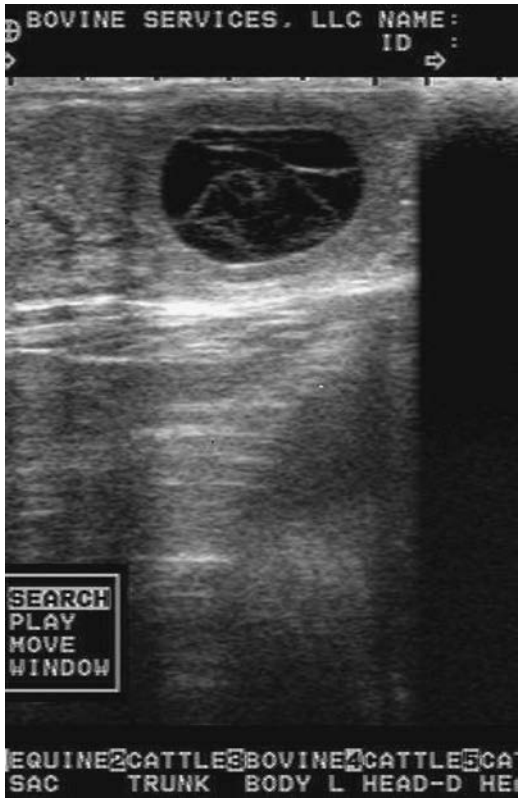


Figure 8.13. Mature cavitary CL. Although there is a large cavity in this CL, there is a significant rim of luteal tissue. This type of CL is often mistaken for a follicular cyst on palpation but can be identified with ultrasound.

well into pregnancy. When a cavity is not present, often there is a hyperechoic central portion representing fibrous tissue. A crown, if present, may or may not be visualized depending on the scanning section.

The proestrus CL again becomes more heterogeneous and smaller as it regresses. This structure often persists through estrus, although it is no longer producing progesterone. Therefore, the presence of a small CL does not necessarily indicate the cow is not near or in heat.

Because ultrasound is so sensitive for identifying CLs, and because the mere presence of a CL does not necessarily mean that it is producing meaningful levels of progesterone, it is advisable to consider the size of the CL when staging the estrous cycle. A 2.2 cm cutoff size significantly improves the specificity of predicting circulating progesterone levels greater than 1 ng/mL (Bicalho et al., 2008). Examination of the uterus and follicular structures, as well as observation of behavior of the cow, are also critical tools for staging the estrous cycle.

Follicles

Research using ultrasound has demonstrated that cows and heifers have two or three (and rarely, four) follicular waves within each estrous cycle (Pierson & Ginther, 1987a,b). Follicular waves also continue during pregnancy. Because follicles are continuously forming and regressing, the mere presence or absence of these structures is meaningless alone. However, when accompanying structures are also considered, the size and number of follicles can be used to estimate the cyclic status and stage of the estrous cycle.

Follicles are always very thin-walled, fluid-filled structures that appear black on the ultrasound monitor. The resolution of good field ultrasound units permits visualization of follicles as small as 2 mm, far more sensitive than rectal palpation. Ultrasound is also much more accurate for differentiating follicular structures from cavitary or soft CLs. Follicles can be classified into the following categories:

1. Small developing follicles. At the beginning of each follicular wave, a group of small follicles is recruited, and they begin to grow. Until about 5 days after the emergence of each follicular wave, these follicles are less than 8 mm, and they probably will not ovulate in response to gonadotropin-releasing hormone (GnRH). This is true for each follicular wave during the cycle.
2. Potentially ovulatory follicles are shown in Figure 8.10. Follicles from 8 mm to about 20 mm have the potential to ovulate in response to GnRH. Approximately 5 days after emergence of a follicular wave, one follicle deviates in size and continues to grow while the others regress. This dominant follicle is able to ovulate in response to GnRH. If it is the dominant follicle from the final follicular wave of the cycle, it will ovulate naturally when progesterone levels decrease as the CL regresses.
3. Atretic follicles. Dominant follicles that mature during periods of high progesterone eventually expe-

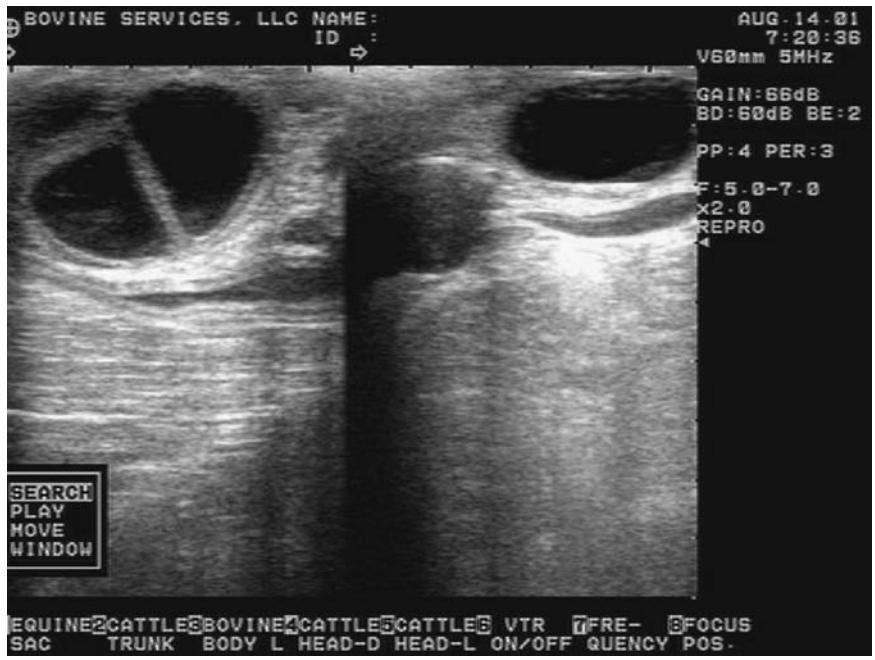


Figure 8.14. Bilateral follicular cysts. Multiple cystic structures on both ovaries and lack of a CL suggest cystic ovarian disease, although a follow-up examination a few days later would be necessary to confirm that no CL develops.

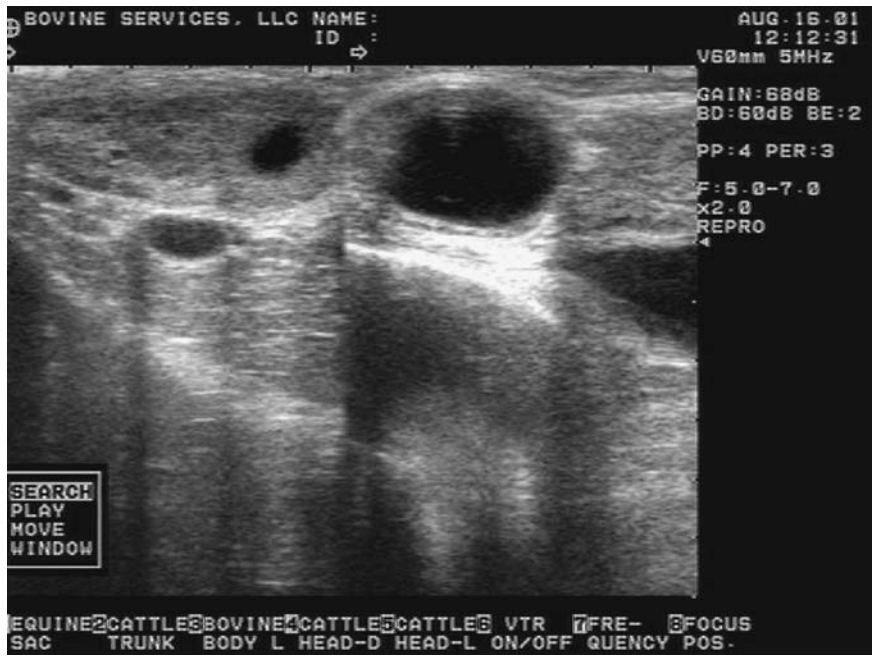


Figure 8.15. Benign follicular cyst on right ovary and two small CLs on left ovary. Large follicular structures in the presence of normal ovarian activity are benign.

rience atresia. Current field ultrasound units cannot differentiate dominant from atretic follicles. However, it might be possible to surmise a follicle is atretic if it is accompanied by a cohort of small follicles representing the next follicular wave.

4. Small anovular follicles (static ovaries). Follicles less than 8 mm in size are unlikely to ovulate. The presence of such follicles in the absence of luteal structures may indicate the animal is anovular, or it may indicate she is in early metestrus. A second examination a few days later will help determine which scenario applies.
5. Large pathologic anovular follicles (traditional follicular cyst shown in Fig. 8.14). The traditional definition of follicular cyst is a fluid-filled, persistent structure greater than 2.5 mm. A more current

definition proposed by Bartolome is the presence of multiple follicles greater than 18 mm, absence of a CL, and lack of uterine tonicity (Bartolome et al., 2005). Palpation has proven nearly useless for differentiating such structures from benign cysts (see #6 later), cavitary CLs, and soft CLs. Only 6 of 51 cows diagnosed as cystic by palpation had functional follicular cysts (Stevenson, 2006). Nineteen of the cows had benign cystic structures accompanied by normal CLs, 12 had normal follicles that ovulated after GnRH, and 14 had cavitary CLs (Stevenson, 2006). A thorough ultrasound examination of both ovaries in their entirety, however, will locate any luteal structures. If no luteal structures accompany the cystic structure, a second examination should be performed a few days later. If there are still no luteal structures, and if the large follicular structure is still present, one can assume the cyst is pathologic.

6. Large benign follicular structures are shown in Figure 8.15. Dr. Paul Fricke at the University of Wisconsin proposes adding this classification based on his field research (P.M. Fricke, "Managing Reproductive Disorders in Dairy Cattle," University of Wisconsin-Madison, unpublished paper). It is quite common to find follicular structures larger than 2.5 cm in normally cycling and even pregnant animals. The presence of a CL, or of a normal size follicle with uterine tone, and behavioral signs of estrus indicates that any accompanying large follicular structure is benign. In the case of large follicular structures seen during early metestrus, when no CL or normal ovulatory follicle is present, a second examination should be performed a few days later to determine if the animal is cycling normally. It is this author's opinion, based on many years of scanning cows, that about 80% of large follicular structures are benign.

Staging the Estrous Cycle Based on Ultrasound Examination

One can estimate stage of the estrous cycle much more accurately by ultrasound than by rectal palpation. However, caution must be used due to the necessity of making assumptions that may or may not be true for an individual animal. For example, a 21-day estrous cycle has been considered normal in the past, but Wisconsin Holsteins have been shown to have a 23-day cycle on average (Savio et al., 1990). The assumption is also often made the adult lactating dairy cows have two follicular waves in each cycle, and heifers have three. This is probably true most of the time, but some cows have three follicular waves (or occasionally four) and some heifers have two (Sartori et al., 2004).

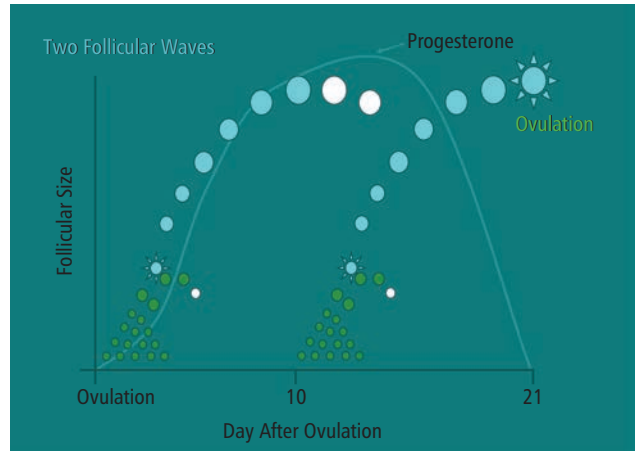


Figure 8.16. Follicular dynamics graph for two follicular waves. Courtesy of Paul Fricke, University of Wisconsin.

For the sake of this discussion, a 21-day cycle and two follicular waves will be assumed. Follicular development can be used to estimate stage of cycle and is shown in Figure 8.16. It is critical that both ovaries and the uterus are examined in their entirety to make estimates of stage of cycle (Adams, 2005).

Metestrus (Days 1–3)

Animals in metestrus (days 1–3 postestrus) will have several small (less than 8 mm) follicles. A visible CL is usually lacking. If present, it is small and heterogeneous. The uterus will be relatively heterogeneous due to edema, and may or may not have a small amount of fluid. In a single examination, metestrus can be difficult to distinguish from anestrus.

Early Diestrus (Days 4–10)

By about day 4, one follicle (sometimes two) can be seen to grow larger than the others, reaching about 8 mm around day 8. At day 4 the other follicles from the first follicular wave are still visible, but they will begin regressing and will be difficult to visualize by day 8. A CL will become readily visible by day 4, often with a cavity. By day 10, the CL is very homogeneous and the cavity has often filled in. The uterus is homogeneous and usually contains no visible fluid.

Late Diestrus (Days 10–18)

A large, mature CL will be seen. A cohort of very small follicles representing the second follicular wave becomes visible beginning about day 10. At about day 12, one follicle grows larger than the others and becomes dominant, just as in the first follicular wave. By day 18, the regressing nondominant follicles are difficult to visual-

ize, but the CL is still present. By day 18, the CL begins to regress, becoming smaller and more heterogeneous. Early CL regression is often difficult to appreciate with field ultrasound units. The uterus is very homogeneous early in this stage, becoming more heterogeneous beginning at about day 16. There is usually no visible fluid in the uterus prior to day 18.

Proestrus (Day 19–Estrus)

A large (16–20 mm) follicle is present, often accompanied by the regressing CL. A small, heterogeneous CL may be visible throughout estrus, but is not producing appreciable progesterone. The uterus will be heterogeneous, contains clear fluid, and has specular reflections on the interior wall as shown in Figure 8.8. With current field ultrasound units, it is not possible to predict the precise time of ovulation in cattle. Current research using color Doppler has shown some promise that this might be possible in the future, however.

Ultrasound with Synchronization Protocols

Once follicular wave dynamics were mapped in the mid-1980s (Pierson & Ginther, 1987a,b) researchers began searching for ways to manipulate the estrous cycle to allow for timed artificial insemination (TAI). Modernization of the dairy industry has led to poorer heat detection due to shorter periods of behavioral estrus in high-producing cows (Lopez et al., 2004), housing that is not as conducive to expression of estrus as pasture, and larger dairies with less intimate human interaction with the cows. Protocols that could avoid heat detection became the Holy Grail for researchers in bovine reproduction. Ovsynch was developed first by Pursley, Mee, and Wiltbank (Pursley et al., 1995), followed by a plethora of other protocols.

There is still no perfect synchronization protocol, but ultrasound can help improve conception rates. Four things have been shown to be important in the success of an Ovsynch protocol, all of which can be at least partially evaluated with ultrasound:

1. The presence of a CL significantly improves pregnancy rates over cows that lack a CL (Galvao et al., 2007). As noted in the preceding section, ultrasound is far superior to palpation to identify CLs.
2. Ovulation to the first GnRH of the protocol (G1) improves pregnancy rate, although less so than presence of a CL (Galvao et al., 2007). This author believes that predicting whether or not a follicle will ovulate to GnRH is difficult even with ultrasound, although properly staging the cycle (see the previous section in this chapter) may provide a reasonable estimation.
3. Related to the first two items, it has been shown that days 5–12 of the estrous cycle is an optimal time to begin Ovsynch for the best conception rates (Vasconcelos et al., 1999). With ultrasound it is relatively easy to identify cows in metestrus and proestrus and remove them from the group beginning Ovsynch. Days 14–18 are more difficult to assess.
4. Related to all of the above, cows with low serum progesterone (cystic, anestrus, metestrus, or proestrus) have lower conception rates to synchronization protocols but may be helped by using an intravaginal progesterone releasing device (controlled internal drug release [CIDR]) with the Ovsynch protocol (CIDRsynch) (Stevenson et al., 2006). Anovular and cystic cows can be readily identified by ultrasound either by evaluating cows for lack of a CLatG1 after being presynchronized, or by two examinations a few days apart if no CL was seen at the first examination in cows that were not presynchronized. As discussed in a previous section, metestrus and proestrus cows can also be more readily identified by ultrasound than by rectal palpation.

Every producer has different desires, needs, and capabilities for his or her reproductive program. Choices are driven by motivation, ability to comply with protocols, herd size, housing type, and so on. The following are some examples of various protocols used by this author's clients, why they were chosen, and how ultrasound is used in four very different herds.

Farm A

Herd description: This is a traditional tie-stall barn with 70 cows. Cows do not have access to pasture. The rolling herd average (RHA) is 29,000# (13,181 kg). Cows are very healthy. The herd owner spends much time with the cows and is very good at detecting secondary signs of heat. The reproductive program is a high priority for this client.

Reproductive program: The herd is visited every 4 weeks for ultrasound examinations. Postpartum examinations are not done because the incidence of subclinical metritis is very low. Because heat detection and uterine health are good, this producer chooses not to presynchronize cows for the first TAI. Instead, only cows not detected in heat between the end of the 60-day voluntary waiting period (VWP) and the next ultrasound visit are examined. Cows with a CL are started on Ovsynch that day. Cows without a CL are started on CIDRsynch if otherwise healthy. Average pregnancy rate in 2008 was an incredible 31%, thanks to excellent herd management, a carefully planned synchronization protocol, and good heat detection of cows that did not conceive.

How ultrasound helps this herd: The accuracy of predicting a CL on G1 improves conception rates to Ovsynch and improves selection of only truly anovular or cystic cows for CIDRsynch. Because the herd is visited only every 4 weeks, the ability to perform pregnancy/open examinations down to 27 days finds open cows sooner. Fetal sexing is helpful for cull decisions because the high pregnancy rate leads to excess females to sell. High production in this herd leads to a high twinning rate. Detection of twins is used to manage those cows differently.

Farm B

Herd description: This modern free-stall facility with 1200 cows has an RHA of almost 30,000# (13,636 kg). Cows are very healthy. The reproductive program is a high priority, but heat detection has been a significant problem in the past. The farm staff is highly competent but very busy.

Reproductive program: Because of the difficulty with heat detection this herd elected to use standard Presynch/Cosynch to set up the first TAI at 72–79 days, with 56 h Cosynch for second and later breedings. The herd manager will not use CIDRs. Cows are hand-sorted into a palpation rail for examinations so the herd manager wishes to keep the number of cows examined weekly to a minimum. Therefore, only cows due for pregnancy examination or recheck/fetal sexing examination are selected. This works well for this herd for three reasons: (1) Excellent cow health means few cows are anovular by the end of the 70-day VWP. (2) Excellent peripartum care minimizes chronic subclinical metritis. (3) Presynchronization and near-perfect compliance with injection schedules makes examination for cyclicity at G1 unnecessary. The average pregnancy rate in 2008 was 23%. The herd manager feels this is acceptable given the labor and frustration saved by eliminating heat detection almost entirely.

How ultrasound helps this herd: Ability to accurately perform pregnant/open examinations at 32–34 days in this fully synchronized herd allows only open cows to be given GnRH to begin the Ovsynch protocol at the appropriate stage of cycle. Fetal sexing is used for cull decisions. High production in this herd leads to a high twinning rate. Detection of twins is used to manage those cows differently.

Farm C

Herd description: This 50-cow herd is housed in a tie-stall barn in the winter and rotationally grazed in summer. RHA is about 23,000# (10,454 kg). The herd owner is nearing retirement and has some physical limitations. He keeps the cows because he likes them, not because he needs the milk income. The reproductive program is not a priority and the owner will not follow an injection protocol.

Reproductive program: The herd is visited every 4 weeks for ultrasound examinations. Cows over 50 days in milk are examined. Open cows with a CL of 2 cm or larger receive a prostaglandin injection, and a note is made on the owner's calendar to watch for heat. Having more than one cow in heat at a time improves heat detection, which is otherwise spotty. The average pregnancy rate from July 2008 to July 2009 was 18%. Certainly, this pregnancy rate could be improved with more frequent herd visits, better heat detection, and a synchronization protocol, but the herd owner prefers a low-input approach.

How ultrasound helps this herd: Pregnancy/open diagnosis down to 27 days compensates partly for less frequent herd visits and spotty heat detection. CL detection and measurement improves the chance that cows will respond to prostaglandin injections. Fetal sexing is used for cull decisions. Twins are not common in this herd, but when detected the owner gives those cows special care.

Farm D

Herd description: This is a registered Holstein dairy whose income from genetics is more important than income from milk. Hence, embryo production and recipient management are more important than a high pregnancy rate. RHA is about 27,000# (12,272 kg).

Reproductive program: See the following section for more details about ultrasound use with embryo transfer protocols. The herd is visited for ultrasound examinations every 2 weeks. Collection of superovulated donor cows and transfer of embryos is scheduled for the day after ultrasound examinations. Superovulated cows are scanned to estimate the number of potential embryos to be recovered the following day. Potential recipients (cows and heifers) are scanned for the quality and location of a CL, if present. Cows ready to begin superovulation are scanned for ovarian structures, both CLs and the number of small follicles available to respond to follicle-stimulating hormone (FSH). All donors and recipients are also evaluated for uterine health. Animals not enrolled in the embryo transfer program are managed as in Herd A.

How ultrasound helps this herd: When palpation was used to select recipients, 30% were rejected. With ultrasound, only 15% are rejected. Embryo pregnancy rates at 30 days remain the same—65% for heifer recipients and 55% for cow recipients. More recipients are used because cavitary CLs are not mistaken for cysts, CLs deep in the stroma are detected, and CLs near benign cysts

can be visualized. Animals with subclinical metritis not detectable by palpation are eliminated from the program until healthy. Evaluation of donor cows, both prior to beginning superovulation and on the day before flush, helps predict the number of recipients needed. The embryo transfer veterinarian enjoys having less work on transfer day and appreciates the good results achieved by working as a team with the ultrasonographer.

Embryo Transfer

Ultrasound enhances every aspect of embryo transfer programs, from predicting the potential response of donors to FSH to choosing recipients. Given the high cost of embryo transfer procedures to clients, the expense of maintaining a pool of recipients, and the high value of each pregnancy achieved, there is no excuse for an embryo transfer practitioner not to use this technology to maximize results. Embryo transfer practitioners can perform the necessary ultrasound examinations themselves or work as a team with an ultrasonographer.

Donor Cows

Donors should receive an ultrasound examination several weeks before beginning superovulation to assess uterine health and ovarian cyclicity. As discussed in previous sections in this chapter, ultrasound can identify more subtle pathology and is more accurate for ovarian structure diagnosis than rectal palpation. This first examination may also include counting the number of small (less than 4 mm) and medium (4–8 mm) follicles on both ovaries. An individual cow is usually consistent in the approximate number of such follicles produced in each follicular wave, allowing the ultrasonographer to estimate the cow's future potential for embryo production (Brad Stroud, DVM, personal correspondence).

Healthy, cycling donors should be examined on day 1 of a superovulation protocol for three reasons. First, the presence of a CL confirms that the cow is in diestrus, the desired time to begin FSH injections. Second, the number of small and medium follicles on both ovaries can be counted to predict how well the donor will stimulate (DesCoteaux et al., 2009). Third, dominant follicles (greater than 8 mm) can be identified and removed by ultrasound-guided follicular aspiration to improve ovulation rate of the remaining follicles by as much as 50% (Guilbault et al., 1991).

Examination on insemination day is optional and, if done, should be by ultrasound. Care must be taken not to rupture follicles, or, worse, displace the large ovary from the ovarian bursa. Hence, donor animals should never be palpated on insemination day. Ultrasound can be safely performed by gently scanning over the ovaries without manipulating them. Naturally, only the total number of follicles can be determined and no estimation of the actual number that will ovulate can be made. Examination of these cows is perhaps best reserved for cases when rare or expensive semen would not be used if the stimulation response is poor.

On embryo collection day ultrasound will more accurately count small CLs, those deep in the stroma, and those obscured by neighboring CLs. Even with ultrasound, however, caution must be used in evaluating fluid-filled ovarian structures. At 7 days postovulation CLs may be small, especially if many are present on the ovary. Some of these will be cavitary with very thin walls of luteal tissue, making them difficult to differentiate from unovulated follicles with standard field machines. Also, some apparently unovulated follicles will indeed have ovulated without subsequent luteinization. On at least a few occasions, examination prior to embryo collection has revealed no apparent corpora lutea and what appeared to be unovulated follicles only to recover numerous viable embryos. In such cases, the number of total ova recovered may exceed the number predicted.

Recipients

Recipients should receive an ultrasound examination prior to being synchronized for receiving an embryo. As with the donor this initial examination will assess uterine health and ovarian cyclicity. Abnormal and anovular animals should be removed from the breeding pool, while normal animals can begin the synchronization protocol.

Brad Stroud, DVM, feels that on embryo transfer day, "An ultrasound examination to confirm the presence of an appropriate CL is as important as the ET gun itself" (DesCoteaux et al., 2009). Far fewer good quality recipients will be rejected when CLs are diagnosed by ultrasound rather than rectal palpation. CLs without an obvious papilla, CLs deep in the stroma, CLs obscured by benign cystic structures, CLs surrounded by several large follicles, and cavitary CLs will be identified and not missed or misdiagnosed. In an unpublished study by Dr. Bill Beal at Virginia Tech, 79% of recipients that would have been rejected based on rectal palpation but were used based on ultrasound examination became pregnant. Dr. Beal recommends using all recipients that have a solid CL greater than 13 mm or a cavitary CL with a luteal rim of at least 3 mm (Beal, W.E., "Practical Applications of Ultrasound in Bovine Embryo Transfer," Virginia Tech, unpublished).

Pregnancy examination of recipients at 21 days post-transfer (28 days gestation) allows the potential for immediate reuse of open animals (Brad Stroud, DVM, personal communication). Open animals are evaluated

for the presence of a CL, and an embryo is implanted that day.

As with any early pregnancy examination, a recheck examination should be done after 60 days. Fetal viability and gender is evaluated at this time. On occasion, when a particular gender of fetus is desired, recipients carrying the undesired gender may be aborted and used again at a later date.

Summary

Ultrasound is a vast improvement over rectal palpation for every portion of the reproductive examination of the bovine. Diagnoses of ovarian structures, uterine pathology, and twins are much improved. Diagnosis of pregnant versus open animals can be done earlier and with better accuracy, allowing open animals to return to the breeding pool earlier. Fetal aging is more accurate. Fetal viability and fetal gender determination, both impossible by rectal palpation, are possible and practical with ultrasound. Adding ultrasound to synchronization and embryo transfer programs can significantly increase profitability due to improved accuracy of ovarian diagnosis and earlier identification of open animals.

Ultrasound units are now reasonably priced and are very small, allowing use in all situations. Table 8.2 lists North American manufacturers and distributors of veterinary ultrasound equipment. Training resources, both courses and audiovisual aids (see Table 8.3), are more available than ever. Producers understand what this technology can do for them and are demanding the service from their veterinarians. They are willing to pay more for more units of more accurate information (Rosenbaum & Warnick, 2004). Today animal scientists use ultrasound for every bovine reproductive study. It is

Table 8.2. Ultrasound equipment suppliers in North America

Aloka (Aloka)
www.aloka.com
800-872-5652

Alpine medical (WED-3000)
www.AlpineMD.com
866-747-7007

BCF (Easi-Scan)
www.bcftechnology.com
800-210-9665
l.com (970)66993

EI medical (Ibex, Bantam)
www.eimedical.com
866-365-6596

Products group international (Honda, Sonosite)
www.productsgroup.com
(800) 336-5299

Universal medical (Various brands)
www.universalultrasound.com
800-842-0607

Veterinary sales and service (Tringa Linear, PIE)
www.vetsales.net
888-234-5999

Table 8.3. Ultrasound training resources

Bovine services
Dr. Jill Colloton
715-352-2232
www.bovineultrasound.net

- *Bovine Reproductive Ultrasound for Veterinarians.* Courses by Jill Colloton, DVM
- *Bovine Reproductive Ultrasonography (DVD)* by Brad Stroud, DVM. Detailed discussion of using ultrasound for bovine reproductive exams with many real-time images.
- *Fetal Sexing Unedited, a Training DVD* by Brad Stroud, DVM. Fifty-two real-time fetal sexing images in quiz form.

Equiservices
Dr. O.J. Ginther
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9

Resynchronization of Estrus, Ovulation, and Timed Insemination in Lactating Dairy Cows

Julian A. Bartolome and William W. Thatcher

Abstract

A reduced interval between artificial inseminations (AIs) is crucial to maintain high reproductive efficiency. Detection of estrus after insemination is the most common, rapid, and low-cost practice to re-artificially inseminate lactating dairy cows. An intravaginal progesterone device with or without estradiol between days 13–14 and 20–21 after AI resynchronizes and facilitates return to estrus detection. However, low expression of estrus of high-producing intensive-managed dairy cows in combination with logistic problems is responsible for low estrus detection and, consequently, extended interval between AI. Therefore, nonpregnant cows need to be detected as soon as possible. Determination of progesterone or pregnancy-associated glycoprotein levels in blood after insemination are methods for early detection of nonpregnant cows. However, ultrasonography and per rectum palpation of the genital tract coupled with resynchronization strategies are the most common methods for rapid re-AI. A gonadotropin-releasing hormone (GnRH) treatment with or without an intravaginal progesterone device 7 days before nonpregnancy diagnosis either by ultrasonography or palpation synchronizes follicular development in such a way that nonpregnant cows can receive prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) and be re-artificially inseminated at detected estrus (artificial insemination at detected estrus [AIDE]) or timed AI (TAI) after synchronization of ovulation with either estradiol or another dose of GnRH. The knowledge on reproductive physiopathology and clinical methods such as rectal palpation and ultrasonography of the genital tract together with management and economic aspects of reproductive efficiency will allow to establish the best resynchronization program for a particular farm.

Introduction

Reproductive efficiency includes reducing the interval between artificial inseminations (AIs) in order to shorten the calving interval. After first service, nonpregnant cows need to be detected in estrus as soon as possible and reinseminated. Detection of estrus is the easiest and most rapid way to identify nonpregnant cows and reinseminate them. However, large dairy herds with intensive management and high milk production have poor estrus detection rate (Nebel et al., 1987). Similarly, pasture-based dairy herds may have management conditions that result in low estrus detection and consequently a long interval between AI. The alternatives for detection of nonpregnant cows and early resynchronization of estrus in order to enhance the chances of estrus detection or for resynchronization of ovulation coupled with timed AI (TAI) are rectal palpation and ultrasonography. The early we detect nonpregnant cows, the shorter will be the interval between AI. Measuring pregnancy-associated glycoproteins (PAGs) or pregnancy-specific protein B (PSPB) have been used to detect early pregnancy (Humblot et al., 1988), but further reasearch is necessary in order to couple this technology with

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resynchronization protocols. Therefore, the efficiency of estrus detection, the use of either rectal palpation or ultrasonography, and the frequency of pregnancy diagnosis will determine the interval between service and detection of nonpregnant cows. The decision to use rectal palpation or ultrasonography and how frequent cows will be evaluated will depend on the level of estrus detection. Re-AI of cows after natural estrus or estrus induced by administration of prostaglandin $F_{2\alpha}$, ($PGF_{2\alpha}$) and alternatives for resynchronization of ovulation and TAI using $PGF_{2\alpha}$, estradiol, gonadotropin-releasing hormone (GnRH), and intravaginal progesterone devices will be discussed.

Intravaginal Progesterone Devices and Artificial Insemination at Detected Estrus (AIDE)

Once cows are inseminated, estrus detection is the most common strategy to identify and reinseminate cows that did not conceive (Macmillan et al., 1999). Visual estrus detection is more efficient when it is combined with detection aids such as tail paints, kamars, pedometers, or the Heatwatch system. However, one of the disadvantages for estrus detection is that 20%–25% of the lactating dairy cows show estrus outside the range of 17–24 days. Administration of an intravaginal progesterone device on days 13–14 post AI and removed on days 20–21 allows for estrus synchronization of nonpregnant cows and enhances the efficiency of estrus detection. A progesterone device applied between days 14 and 17 after first AI and removed on day 21 increased the percentage of cows inseminated on days 23 and 24, did not affect pregnancy to previous service, and generated similar conception rate for resynchronized service than cows in the control group (Macmillan & Peterson, 1993). In another study, detection of estrus within 3 days after device removal was 34.1% for treated and 19% for control cows, and conception rate for resynchronized services were similar for treated and control cows (Chenault et al., 2003).

Administration of 1 mg of estradiol benzoate on day 13 post AI synchronizes follicular growth and next estrus (Burke et al., 2000). This treatment in combination with sponges impregnated with medroxyprogesterone acetate increased the number of cows inseminated between days 18 and 25 (Cavestany et al., 2003). The insertion of an intravaginal progesterone device alone or in combination with an estrogen treatment at device insertion or removal (or 24 h after removal) can synchronize the return to estrus (Macmillan et al., 1999; El-Zarkouny et al., 2001, 2002). These strategies that can result in normal (El-Zarkouny et al., 2001; Moreira et al., 2001) or low fertility (El-Zarkouny et al., 2001; Cavestany et al., 2003) have additional disadvantages such as the risk of estrogen treatment in a potentially pregnant cow and requirement for estrus detection. Therefore, even if these treatments improve estrus detection, high-producing dairy cows under intensive management may have poor estrus expression, and alternatives including TAI will be necessary. In order to synchronize estrus and ovulation, $PGF_{2\alpha}$ needs to be administered and, therefore, rectal palpation or ultrasonography is necessary to identify nonpregnant cows.

Resynchronization of Cows Detected Nonpregnant by Rectal Palpation

Pregnancy diagnosis using palpation per rectum of the uterus has been proved to be accurate and harmless at 34 days post service. Nonpregnant cows at rectal palpation are cows that did not conceive or conceived but lost pregnancy and were not detected in estrus. Rectal palpation, in addition to detection of nonpregnant cows, allows for characterization of the estrous cycle based on clinical findings on the ovaries and uterus (Zemjanis, 1962). Approximatly 50%–60% of nonpregnant cows at rectal palpation present a corpus luteum (CL) and can be treated with a luteolytic dose of $PGF_{2\alpha}$ and induce estrus. The positive predictive value of rectal palpation to detect a CL is 80% (~90% by ultrasonography), and the luteolytic efficacy of $PGF_{2\alpha}$ is 76.9% between days 5 and 9, 86.4% between days 10 and 13, and 95.7% between days 14 and 19 (Xu et al., 1997). The interval between $PGF_{2\alpha}$ treatment and estrus expression ranges from 36 to 168 h depending on the stage of the follicular wave at the time of treatment (King et al., 1982). Nonpregnant cows without a CL at rectal palpation will not respond to a $PGF_{2\alpha}$ treatment and therefore could either be left without treatment for estrus detection or be treated with GnRH with or without a progesterone device and receive $PGF_{2\alpha}$ 7 days later.

Again, this resynchronization strategy relies on estrus detection that will have to be close to 70%, otherwise AIDE will have to be combined with TAI in order to increase re-AI efficiency. Synchronization of ovulation and TAI using the Ovsynch protocol (Pursley et al., 1995) generates acceptable pregnancy rate in cows with normal estrous cycle (Burke et al., 1996) and those with follicular cystic degeneration (Bartolome et al., 2000). Another alternative, and considering that the Ovsynch protocol is more efficient when it is initiated within days 5–10 of the estrous cycle (Moreira et al., 2001), in herds with a reasonable estrus detection, cows with a CL could be treated with $PGF_{2\alpha}$, and those not inseminated within 12 days could be subjected to the Ovsynch protocol (Bartolome et al., 2002). Cows without a CL (proestrus,

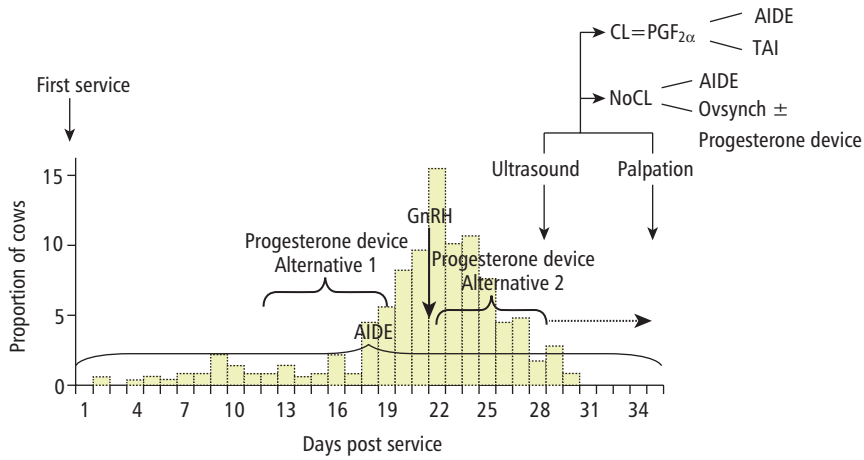

Figure 9.1. Distribution of return to estrus and alternatives for resynchronization in lactating dairy cows.

estrus, metestrus, anestrus, or with ovarian cysts) could be treated with the Ovysnch protocol with or without a progesterone device or be treated with GnRH and then receive the Ovsynch protocol 8 days later. A different alternative to prevent or deal with cows without a CL at nonpregnancy diagnosis is to administer GnRH 7 days before pregnancy diagnosis or include a progesterone device with the Ovsynch protocol (Dewey et al., 2009). Cows that received GnRH 7 days before the Ovsynch protocol at nonpregnancy diagnosis using rectal palpation at day 38, or cows that received a progesterone device with the Ovysnch protocol on Day 38 had a better conception rate to resynchronized service compared with cows that received only the Ovsynch protocol (33.6% for GnRH+Ovsynch, 31.3% for Ovsynch+controlled internal drug release [CIDR], and 24.6% for Ovsynch). In order to reduce time between AI, the Ovsynch protocol with a progesterone device could be initiated 7 days before pregnancy diagnosis by rectal palpation. Considering the distribution of estrus after first AI, the initiation of Ovsynch at 28–30 days after first service would mean most cows would be at approximately days 6–8 of the cycle. GnRH injection would induce ovulation of a first wave follicle and initiate recruitment of a new follicular wave under a high progesterone environment. At 35–37 days after first service, $PGF_{2\alpha}$ can be administered in cows diagnosed nonpregnant by rectal palpation. These cows would then be injected with GnRH and TAI at 56 h and 72 h after the $PGF_{2\alpha}$ injection, respectively.

The disadvantage of using rectal palpation to identify nonpregnant cows is that the interval between AI will be extended especially if the frequency of palpations is not high and estrus detection on the farm is low. In addition to initiating the TAI protocols 7 days before and increasing the frequency of pregnancy diagnosis, the use of ultrasonography can reduce to another 7 days the re-AI of nonpregnant cows.

Resynchronization of Cows Detected Nonpregnant by Ultrasonography

Pregnancy diagnosis by ultrasonography of the genital tract can be done 25 days post service (Pierson & Ginther, 1984b). Ultrasonography of the ovaries (Pierson & Ginther, 1984a) and uterus (Pierson & Ginther, 1987), in combination with per rectum palpation (Zemjanis, 1962), allows for characterization of stages of the estrus cycle as shown in Table 9.1. Nonpregnant cows at ultrasonography could receive the same resynchronization protocols previously discussed for rectal palpation. In contrast to the dispersion of estrous cycle stages in cows detected at 34 days post AI, estrous cycle stages will be more concentrated in cows detected nonpregnant by ultrasonography at days 25–28 as shown in Figure 9.1. However, the distribution of stages or abnormalities of the estrous cycle in high-producing lactating cows after ultrasonography on day 28 was 46.1% for diestrus, 14.8% metestrus, 22% proestrus/estrus, 14.4% ovarian cysts, and 2.7% anestrus (Bartolome et al., 2005a).

In herds with poor estrus detection, applying TAI protocols such as Ovsynch or Heatsynch to nonpregnant cows at ultrasonography have achieved pregnancy rates of 25% in high-producing cows during summer time in Florida, USA. It is interesting to mention that cows in metestrus had higher pregnancy rates with the Heatsynch protocol, and cows with ovarian cysts responded better to the Ovsynch protocol (Bartolome et al., 2005a). Probably, for cows in metestrus, the GnRH was not efficient to synchronize a follicular wave, they ovulated

Table 9.1. Stages and abnormalities of the estrous cycle based on clinical findings at palpation and ultrasonography of the genital tract

	Clinical findings	
Stage	Ovaries	Uterus
Diestrus	Functional CL Follicles > 10 mm	Moderate tonus
Metestrus	Corpus hemorragicum Follicles < 10 mm	Edema and moderate tonus
Proestrus/estrus	Regressing CL Follicle > 18 mm	High tonus
Ovarian cysts	Absence of CL Multiple follicles > 18 mm	Flaccid
Anestrus	Absence of CL Follicle < 18 mm	Flaccid

Source: Adapted from Zemjanis (1962) and Pierson and Ginther (1987).

earlier, and were benefited by the estradiol treatment of the Heatsynch protocol (in fact, most of the cows in metestrus were artificially inseminated on day 9 of the protocol). In contrast, cows with ovarian cysts have more chances to respond to the initial GnRH and benefited from the GnRH to synchronize ovulation of the Ovsynch protocol since they have compromised the mechanism of positive feedback of estradiol on GnRH release. Since the stage of the estrous cycle could affect the response to a resynchronization protocol, ultrasonography in combination with rectal palpation can be used to assign protocols accordingly. In herds with acceptable estrus detection, cows with a CL could be assigned to $PGF_{2\alpha}$ and AIDE, and cows without a CL and either in proestrus, estrus, anestrus, or with ovarian cysts could be assigned to GnRH with or without a progesterone device, 7 days later $PGF_{2\alpha}$ and then AIDE. The progesterone device could be inserted 24 h after GnRH to enhance the efficacy of GnRH to induce ovulation of a dominant follicle and synchronize the follicular wave. Cows in metestrus will probably benefit by initiating the resynchronization protocol using a progesterone device combined with estradiol benzoate that will be more effective to synchronize the follicular wave since it will cause atresia of follicles during initial stages of the follicular wave. Again, in herds with poor estrus detection, TAI will have to be part of the program. TAI after $PGF_{2\alpha}$ in cows with a CL has been tried either using estradiol 24 h after $PGF_{2\alpha}$ and TAI 60 h post $PGF_{2\alpha}$ (Stevenson et al., 2003) or GnRH and TAI at 72 h in cows not detected in estrus (Archbald et al., 1992). However, these alternatives do not synchronize the follicular wave and may result in reduced fertility. The alternative again will be initiating the protocols 7 days before pregnancy diagnosis (Moreira et al., 2001). Initiation of the Ovsynch protocol on day 21 post AI and ultrasonography on day 28 showed that this protocol did not affect previous pregnancy, and fertility was similar to cows that initiated the protocol on day 28 (Chebel et al., 2003). Based on the distribution of estrus after AI, the ideal time to initiate the Ovsynch protocol would be day 23 since most cows will be in proestrus, and in fact reasonable pregnancy rates have been achieved by initiating the Ovsynch protocol on day 23 post AI with ultrasonography at day 30 (Bartolome et al., 2005b). Again, a negative effect was not observed on previous pregnancy for cows that became pregnant at ultrasonography.

Administering GnRH 7 days before ultrasonography changed the proportion of stages of the estrous cycle at the time of nonpregnancy diagnosis, and 73% of the cows were in diestrus, 6.4% in metestrus, 9.8% in proestrus, 8.6% with ovarian cysts, and 1.7% in anestrus. In addition, 50% of the cows with follicular cysts showed partial luteinization of follicles. There was a clear increase of cows in diestrus (46% without GnRH and ultrasonography on day 28 and 73% with GnRH on day 23 and ultrasonography on day 30); however, some cows still will not have a CL at nonpregnancy diagnosis. In order to enhance the response to GnRH on day 23, an intravaginal progesterone device was inserted between days 14 and 23; however, the proportion of cows with CL at ultrasonography did not change (Bartolome et al., 2009). Therefore, the alternative is to include a progesterone device together with the GnRH on day 23, and the totality of nonpregnant cows at day 30 could be timed-inseminated regardless of the presence of CL. Using this strategy, pregnancy rate was about 30% in cows with and without a CL.

Summary

Early detection of nonpregnant cows and re-AI is an important aspect of reproductive management of dairy cows in order to increase reproductive efficiency. Detection of estrus is the simpler and most rapid way to reinseminate cows that did not conceive to a previous service and, therefore, dairy farms need to make the effort to maintain a reasonable efficiency on this task.

However, since estrus expression in high-producing dairy cows is poor and management conditions could affect the efficiency of estrus detection, estrus resynchronization will be necessary to maintain a short interval between AI. The ideal situation will be to detect nonpregnant cows as early as possible and to have a CL or high progesterone levels and a synchronized follicular wave to allow re-AI soon after nonpregnancy diagnosis. Rectal palpation and ultrasonography are the two most common methods of detection of nonpregnant cows. Herds with acceptable estrus detection rate (pasture-based or low-producing herds) could use more conservative programs combining AIDE and TAI. Nonpregnant cows with a CL could receive $PGF_{2\alpha}$ and AIDE, and cows without a CL could receive a TAI protocol. Herds with poor estrus detection (high-producing intensive-managed herds) may have to increase the frequency of pregnancy diagnosis and use resynchronization protocols that allow for TAI. Administration of GnRH and a progesterone device 7 days before pregnancy diagnosis and initiating the treatment considering the distribution of estrus after previous service seem to be the best approach for rapid re-AI. The knowledge on reproductive physiopathology and clinical methods such as rectal palpation and ultrasonography of the genital tract together with management and economic aspects of reproductive efficiency will allow the establishment of the best resynchronization program for a particular farm.

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10

Diseases that Affect the Reproductive Performance of Dairy Cattle

Carlos A. Risco and Pedro Melendez Retamal

Abstract

From an economic point of view, a successful reproductive program on a dairy farm increases the number of pregnant animals in a timely manner at the end of the voluntary waiting period. Peripartal diseases and those that occur during lactation disturb this process by affecting health, delaying resumption of cyclicity, and lowering conception risk and embryo survival. This chapter discusses common diseases that affect the reproductive process of lactating dairy cows.

Introduction

Reproductive performance in lactating dairy cows should be viewed as a process that involves estrus detection, breeding, conception, and pregnancy maintenance. From an economic point of view, the outcome of this process in a dairy farm is to increase the number of pregnant animals in a timely manner at the end of the voluntary waiting period. Diseases that occur throughout lactation can have a major impact on this outcome by affecting cyclicity, conception, and embryo survival. This chapter discusses common diseases that affect the reproductive performance of lactating dairy cows within the content of this process.

Hypocalcemia-Related Diseases

The total blood calcium concentration in cows is about 10 mg/dL (~5.0 mg/dL ionized calcium). During calving or shortly thereafter, hypocalcemia is inevitable in the dairy cow and is characterized by a plasma calcium concentration <7.5 mg/dL (Goff, 2000). Milk fever or parturient paresis is considered the clinical manifestation of hypocalcemia, and the decreased blood calcium content is accentuated in affected cows. Clinical signs associated with milk fever occur as progressive muscular weaknesses from changes in neuromuscular tone and range from tremors during the early stages to flaccid paralysis and eventually coma (Van Saun, 2007). Milk fever has been associated with dystocia, retained fetal membranes, uterine infection, and mastitis, diseases that lower fertility in cattle (Grohn et al., 1990).

Hypocalcemia affects the normal function of organs that contain smooth muscle, such as the abomasum and rumen, without causing the animal to become paretic (Huber et al., 1981). This condition is referred to as subclinical hypocalcemia and has been associated with various periparturient disorders such as uterine prolapse (Risco et al., 1984), retained fetal membranes (Risco et al., 1994; Meléndez et al., 2002), and displaced abomasum (Massey et al., 1993). The practice of feeding anionic diets to prepartum dairy cows has lowered the incidence of clinical hypocalcemia in dairy farms to a point where milk fever is not considered a major health problem in dairy farms that feed these types of diets. In contrast, it is the opinion of the authors that subclinical hypocalcemia continues to be a common problem affecting postpartum cow health. Goff & Horst (1998) reported that 10%–50% of cows

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remained subclinically hypocalcemic during the first 10 days postpartum. In cows with retained fetal membranes and uterine prolapse without signs of milk fever, hypocalcemia was observed during the first 7 days postpartum (Risco et al., 1994).

Hypocalcemia during parturition increases plasma cortisol, which is a major contributor to immune suppression. Typically, cows have a three- to fourfold increase in plasma cortisol as a component of the parturition process. However, subclinically hypocalcemic cows can have a five- to sevenfold increase in plasma cortisol on the day of parturition, and cows with milk fever may exhibit plasma cortisol concentrations that are 10- to 15-fold higher than precalving plasma cortisol concentrations (Horst & Jorgensen, 1982). Because immune suppression has been reported to begin 1–2 weeks prepartum (Horst & Jorgensen, 1982; Kehrli et al., 1998) and the surge of cortisol is confined to the day of parturition, cortisol probably plays more of a contributing than a causal role in immune suppression.

The response of immune cells is complex. Generally, a compound such as a cytokine will bind to receptors on the immune cell surface, which then initiates an increase in intracellular calcium concentration, which acts as a second messenger to alter intracellular metabolism, initiating an immune response of the cell. The source of calcium for this response is from the endoplasmic reticulum and mitochondria of the cell. Hypocalcemia appears to interfere with the activation of immune cells (Kimura et al., 2006). As hypocalcemia develops in the extracellular fluid, there is also a concomitant reduction of calcium in the endoplasmic reticulum of the immune cells. As a result of the insufficient stores of calcium in the endoplasmic reticulum, the response of immune cells to activating stimuli is blunted in cows with hypocalcemia. This effect of hypocalcemia on immune function may help explain the association of milk fever with immune-mediated diseases such as retained fetal membranes and mastitis.

Treatment of Hypocalcemia

In cases of hypocalcemia, calcium therapy is directed at replacing and maintaining normal plasma calcium concentration in clinical or subclinical cases of hypocalcemia. In cases of milk fever, immediate intravenous calcium therapy to prevent death is warranted. Additionally, in those cows at risk to develop subclinical hypocalcemia (retained fetal membranes, inappetance), calcium therapy would help restore blood calcium concentration and promote normal function of calcium-dependent organs.

Most commercial intravenous solutions contain either calcium gluconate (9.3% Ca), which is a less caustic form compared with $CaCl_2$, or calcium borogluconate (8.3% Ca), which are more soluble and stable solutions (Van Saun, 2007). The calcium replacement needs for hypocalcemia are around 10 g. Most commercial calcium solutions contain between 8.5 and 11.5 g of calcium per 500 mL. For example, a standard intravenous dose of 500 mL of a 23% calcium gluconate solution provides 10.8 g of calcium, restoring plasma calcium concentration to normocalcemic levels.

Soluble calcium salts for oral supplementation are commercially available to treat subclinical hypocalcemia and prevent relapses in clinical hypocalcemia cases after calcium therapy. Oral calcium compounds have been developed to take advantage of the passive diffusion of ionized calcium across cellular tight junctions in the rumen and intestines. Passive diffusion is dose-dependent, and dosages of 50–75 g of calcium are needed to drive the passive absorption process (Goff & Horst, 1993). Oral calcium supplements maintain elevated calcium blood concentration for 5–7 h (Goff & Horst, 1993). Caution should be exercised in combining intravenous and oral calcium treatments because of the increased risk of cardiotoxicity and a delaying stabilization of calcium homeostasis. The following compounds are oral calcium supplements commonly used by veterinarians:

- Calcium chloride (36% Ca): This is effective but can induce metabolic acidosis and therefore should be used with caution in cows fed an anionic diet. In addition, this compound is corrosive and may result in esophageal tissue necrosis.
- Calcium propionate (21% Ca): This compound may be preferred because it is less irritating, does not induce metabolic acidosis, and provides propionate as a glucose precursor. Supplying 250–400 g of calcium propionate provides 54–75 g of calcium, respectively. Oral administration of 510 g of calcium propionate supplies 100 g of calcium for absorption from the gut, which is equivalent to an intravenous dose of 500 mL of a 23% calcium gluconate solution, providing 10.8 g of calcium in blood.

Diseases Related to Negative Energy Balance

Prior to parturition, a depression in feed intake occurs in dairy cows, and after calving they mobilize fat as well as protein reserves. Consequently, many dairy cows are in a negative energy balance and may develop subclinical ketosis during early postpartum; uterine health can be compromised, predisposing cows to uterine infections.

Energy balance near calving was associated with uterine health disorders and fever in Holstein cows (Hammon et al., 2006). Cows with fever (days 1–10 postpartum) and endometritis (cytology at 4 weeks postpartum) experienced lower dry matter intake from −1 week to +5 weeks of calving and were ketotic from −2 to +4 weeks from calving. Cows that were ketotic during postpartum had suppressed neutrophil function. The authors concluded that uterine infections are preceded by negative energy balance prior to calving and extend into early lactation.

Postpartum reproductive function can be divided into recrudescence of ovarian follicular activity, ovulation, and formation of fully functional corpora lutea that will maintain a pregnancy. Cows expressing one or more estruses during the first 30 days postpartum had improved pregnancy rates to first service compared with anovular cows (Thatcher & Wilcox, 1973). This observation indicates that the physiological and hormonal events associated with estrus help restore uterine and ovarian function to a state conducive to the establishment of pregnancy.

The proportion of cows that remain anovular by 60 days postpartum ranges from 20% to 40% and can be as high as 60% (Lima et al., 2009). The severity and duration of negative energy balance postpartum is a major factor that influences ovarian activity and resumption of cyclicity postpartum in dairy cows. Butler (2000) determined that the approximate interval from the nadir of negative energy balance to occurrence of first postpartum ovulation is 10 days. The effect of energy status on integrated ovarian activity during early lactation was assessed in 54 Holstein cows during the first 9-week postpartum (Staples et al., 1990). Twenty-eight percent of the cows ($n = 15$) were anovular (did not cycle) for the 9-week postpartum period. These cows were compared with two cycling groups: a group of 25 cows that resumed cyclicity within 40 days after parturition and a second group of 14 cows that resumed cyclicity between 40 and 63 days postpartum. Both the later cycling and noncycling cows were in progressively negative energy states; that is, they continued to be in a more negative energy state in the second week than in the first week. This was especially true for the anovular cows. Intake of feed by anovular cows continually lagged behind that of cycling cows. Not only did anovular cows eat less at week 1 postpartum, but the difference between them and cycling cows became greater as time went on. On the average, anovular cows ate between 2.5 and 3.6 kg less feed per day than cycling cows. The cows that ovulated earlier started their recovery to a positive energy state after the first week. The marked deficit in early energy status for the anestrous cows in this study exerted a marked carryover effect on conception. Only 33% (5/15) of anestrous cows eventually conceived, compared with 84% (21/25) and 93% (13/14) for early and late cycling cows, respectively. Results from the Staples et al. (1990) study corroborate with those from Santos et al. (2009), who reported that dairy cows classified as cyclic at 65 days postpartum had significantly greater pregnancies per insemination at 30 (41.1% vs. 29.0%) and 58 (35.8% vs. 24.8%) days after first postpartum insemination compared with cows that remained anovular by 65 days postpartum.

Body Condition Scores (BCSs)

Body condition scores (BCSs) postpartum are related to the magnitude and severity of negative energy balance and are used to assess body reserves, particularly fat. A scale of 1–5 with increments of 0.25 unit is recommended for dairy cattle (Ferguson et al., 1994). Cows that experience BCS loss early in lactation are in a greater negative energy balance and are more likely to be less fertile. Domecq et al. (1997) investigated the relationship between changes in BCS during the dry period, early lactation, and conception to first service in 720 Holstein cows. This study concluded that cows that lost 1 point of BCS in the first month of lactation were 1.5 times less likely to conceive than were cows that did not lose 1 point of BCS, and that the energy balance during the dry period and early lactation, as monitored by BCS, was more important to conception to first service than were health disorders or other risk factors evaluated. Pregnancy rates to timed insemination for first service in lactating dairy cows were compared in cows with BCS <2.5 (low BCS group) versus ≥2.5 (control group) using a 1–5 scale (Burke et al., 1997). Pregnancy rates were less for the low BCS group compared with the control group at day 27 (18.11% ± 6.10; 33.83% ± 4.55) and at day 45 (11.14% ± 5.49; 25.64% ± 4.10). Rates of cumulative pregnancies through either 120 or 365 days postpartum were lower for low BCS cows. Based on these results, Thatcher et al. (1999), using a dynamic programming model, calculated the additional revenue per cow per year in dollars of various scenarios in which the percentage of the herd with low BCS (<2.5) varies. There was an increase in net revenue per cow per year, related to more pregnancies, of $10.33 between a herd of cows with a low body condition rate of 10% versus 30%. The data were unique to the commercial herd of cows in which the study was completed. However, the study provides the relative costs under various herd management scenarios for body condition. The general recommendation made for BCS scores in dairy cows are, at calving, 3.50–3.75, with no

Table 10.1. Metabolic profiling and dairy production records to evaluate herd risk for ketosis

Profile or record	When	Number of animals	Risk for ketosis
NEFA	Prepartum (–14 to –3 days) Postpartum (<30 days)	More than two out of 12 cows sampled have 0.4 mEq/L prepartum or 0.7 mEq/L postpartum	Yes
BHB	Early postpartum	More than two out of 12 cows sampled of 10 or 12 cows have >14.5 mg/dL (1400 μmol/L)	Yes
Milk fat composition	First test day	20% or greater of cows have elevated milk fat (Holsteins, 5%; Jerseys, 6%)	Yes
Fat-to-protein ratio in milk	First test day	40% of cows with 1.33	Yes

NEFA = nonesterified free fatty acids; BHB = beta hydroxy butyrate.

more than 1 BCS point loss during the first 60 days postpartum.

Herd Diagnostics for Ketosis Risk

Transition cow management is dynamic in the sense that the number of cows that enter and leave the transition period changes, and errors in feeding can occur, predisposing cows to subclinical ketosis after parturition. Therefore, from a production medicine perspective, evaluation of herd risk for ketosis should be routinely conducted on dairy farms to determine whether or not parturient cows are transitioning well into lactation. That is, if the risk for ketosis is present, evaluation of feeding and management practices of the transition period is indicated to implement corrective practices. The premise for determination of herd risk for ketosis is based on selective metabolic profiling and dairy production records evaluation and has been reviewed by Van Saun (2007) (see Table 10.1).

Treatment of Cows with Ketosis (Clinical or Subclinical)

The major objective in ketosis therapy is to reestablish normal feed intake. This requires resolution of hypoglycemia and hyperketonemia. It is vital to identify and to treat concurrent conditions with ketosis (uterine infection, displaced abomasum, mastitis) and to address predisposing factors at the herd level.

Glucose or Dextrose

Many products containing glucose are approved for treatment of ketosis in cattle. A single dose of 500 mL of 50% dextrose (dextrorotatory isomer of glucose) intravenous, supplying 250 g of glucose, is the most common therapy. However, about 80% is lost in the urine due to transient hyperglycemia (cattle have a relatively low renal threshold for glucose; 110 mg/dL) and blood glucose is usually back to preinfusion levels by 2 h after injection. The cow requires 50–70 g/h for maintenance and 200 g/h for high milk production. Therefore, the amount of glucose supplied by 500 mL of 50% dextrose is only a small fraction of the daily requirement. However, dextrose or glucose is an effective therapy for ketosis and results in reduced gluconeogenesis and ketogenesis. Rather than contributing to glucose requirements of the cow, intravenous administration of these products is thought to act by causing a transient hyperglycemia that drives reestablishment of normal patterns of energy metabolism.

Glucose Precursors

Propylene glycol (PG) is only beneficial if the liver is functional, as PG must be metabolized, and rumen motility is present to aid in mixing and absorption. A small amount is converted to propionate in the rumen, but most is absorbed as PG and is metabolized to glucose in the liver. Maximum PG blood levels occur within 30 min of administration, and maximal conversion to glucose occurs about 4 h after administration. The dose is 250–400 g (8–14 oz) twice daily for up to 3 days. PG may suppress appetite at high doses and is toxic at very high doses (toxic dose $[TD]_{50}$ is 2.6 g/kg, equivalent to 43 oz of propylene glycol in a 500-kg cow). Calcium propionate at a dose of 510 g is appropriate and is perhaps more indicated because cows with ketosis may also be hypocalcemic.

Glycerol (same dose as PG) and *sodium propionate* can also be used as glucose precursors, but both are considered inferior to PG.

Glucocorticoids induce hyperglycemia in cattle by changes in glucose distribution and utilization rather than by induction of gluconeogenesis. They decrease milk production (and therefore glucose demand) by at least 20%; this may be their major effect. Some gluconeogenic activity occurs (mobilization of amino acids and conversion to glucose in the liver). Glucocorticoids may also stimulate appetite. These should be used cautiously in cows with a concurrent infectious disease, although a single dose of glucocorticoids is unlikely to have a marked immunosuppressive effect. The recommended dose of glucocorticoids for the treatment of ketosis are 10–20 mg IM, repeated once in 24 h if needed.

Uterine Infections

Economic costs due to uterine disease are related to infertility, increased culling for failure to conceive, reduced milk production, and the cost of treatment. A single case of metritis has been calculated to be about €292 (Drillich et al., 2001). In the European Union (EU) there are 24,146,000 dairy cows (Ataide Dias et al., 2007) and in the United States 8,495,000 (USDA ERA [United States Department of Agriculture Economic Research Service], 2009). Sheldon et al. (2009), using an incidence rate of 20% for metritis, calculated the annual cost of uterine disease in the EU as €1.411 billion and in the United States as $650 million.

A major risk for uterine infection in dairy cows is retained fetal membranes (Grohn et al., 1990) and a diagnosis is generally made when membranes are retained from 12 to 24 h after parturition. The option of no treatment at the time of retained fetal membranes diagnosis has become a common practice on many dairies. Cotyledonary membranes will separate from caruncular tissue, and complete expulsion occurs within days after diagnosis. However, cows that retain fetal membranes can develop systemic signs related to uterine infections after initially being left untreated. Consequently, producers should monitor cows with retained fetal membranes for systemic disease and provide prompt treatment. Conversely, initiating antimicrobial treatment on cows diagnosed with the disease even without signs of systemic illness is advocated by some veterinarians to prevent uterine infections and related diseases. The purpose of systemic antimicrobial therapy is not to aid in the expulsion of the membranes but rather to prevent uterine infection. Systemic administration of ceftiofur in dairy cows affected with dystocia, retained fetal membranes, or both reduced the incidence of metritis by 70% compared with retained cows not treated with antibiotics or those treated with estradiol cypionate (Risco & Hernandez, 2003).

Uterine infections within a week of parturition are present in up to 40% of dairy cows; herd rates for clinical signs between 36% and 50% have been reported (Markusfeld, 1987; Zwald et al., 2004), and up to 21% of animals have signs of systemic illness such as fever (Drillich et al., 2001). The veterinary literature contains numerous reports and studies suggesting that uterine infections decrease milk yield and fertility. However, in these reports, the types of uterine infections were not distinguished and were classified as a disease complex ranging from cows that appeared normal to those affected by life-threatening sepsis. Furthermore, when describing uterine infections, the terms "metritis" and "endometritis" have been used without considering clinical findings and effect on fertility. These inconsistencies in definitions have contributed to uncertainty among veterinarians in the definition used to diagnose and treat uterine infections.

Definition and Clinical Features of Uterine Infections

Metritis

This condition is a result of a severe inflammation of the endometrial mucosa and submucosa, muscularis, and serosa. It generally occurs during the first week to 21 days after calving and is associated with dystocia, retained fetal membranes, and calving trauma. Affected cows may be septic and present with fever, depression, anorexia, and reduced milk yield. In addition, a copious fetid vaginal discharge may be present. The severity of disease is categorized by clinical signs (Sheldon et al., 2009). Cows with an abnormally enlarged uterus and a purulent uterine discharge without systemic signs of illness are classified as grade 1. Animals with additional signs of systemic illness, such as decreased milk yield, dullness, and fever >39.5°C, are classified as grade 2. Animals with signs of toxemia (inappetance, cold extremities, depression, and/or collapse) are classified as grade 3, which have a poor prognosis. Clinical metritis grades 2 and 3 can be life-threatening diseases that warrant systemic antibiotic treatment.

Clinical Endometritis

This condition is characterized by the presence of purulent (>50% pus) or mucopurulent (approximately 50% pus, 50% mucus) uterine exudates in the vagina, 21 days or more postpartum, without abnormally enlarged uterine horns (Sheldon et al., 2009). These criteria to diagnose clinical endometritis have been validated by correlating clinical findings with an increased interval from calving to conception (LeBlanc et al., 2002).

Furthermore, the evaluation of uterine horn size per rectal palpation to diagnose clinical endometritis lacked diagnostic accuracy in predicting subsequent reproductive performance. Luteolysis in cows with clinical endometritis appears to be disrupted, and luteal phases are extended (persistent corpus luteum) because inflammatory responses switch the endometrial epithelial secretion of prostaglandins from the F to the E series (Herath et al., 2009). As a consequence to a persistent corpus luteum, progesterone continues to dominate the uterus and suppresses the uterine defense mechanism, and the cow may develop pyometra (Hussain, 1989).

Subclinical Endometritis

This condition has been described as inflammation of the endometrium in the absence of purulent material in the vagina that results in significant reduction in reproductive performance (Sheldon et al., 2009). Neutrophils are the primary response against pathogenic bacteria of the postpartum uterus, resulting in an increase in polymorphonuclear (PMN) cells within the uterine lumen. A cytological evaluation measures the proportion of PMN cells present in the uterine lumen. Subclinical disease is defined by PMNs >5.5% and 10% of cells in uterine cytology samples collected by flushing the uterine lumen or by endometrial cytobrush, in the absence of clinical endometritis 20–30 days postpartum (Kasimanickam et al., 2005).

Treatment and Management of Uterine Infections

Treatment of uterine infections continues to be a contentious topic among veterinarians, perhaps because of the lack of precise diagnostic criteria and lack of controlled trials in which various therapeutic options have been rigorously compared. Therapy for uterine infection includes intrauterine therapy of antibiotics, systemic antibiotics, supportive therapy, and hormone therapy (Hussain & Daniel, 1991).

Oxytetracycline has been recommended for intrauterine therapy for postpartum cows affected with metritis or clinical endometritis caused by *Arcanobacterium pyogenes*. However, a study that isolated *A. pyogenes* recovered from the uterus of cows showed that they were resistant to oxytetracycline, and intrauterine treatment with large doses did not affect the frequency of *A. pyogenes* isolation (Cohen et al., 1995). Furthermore, many preparations of oxytetracycline are irritating and cause chemical endometritis. It should be mentioned that antibiotics are not approved in the United States for intrauterine administration to lactating dairy cows. Intrauterine administration of antibiotics can result in contamination of milk, and appropriate withdrawal times have not been determined (Bishop et al., 1984).

A variety of broad-spectrum antibiotics has been recommended for parenteral administration to cows with metritis. Penicillin or one of its synthetic analogs is most commonly recommended (20,000–30,000 U/kg bid). Oxytetracycline is probably not a good choice for systemic administration because of the difficulty in reaching the minimal inhibitory concentration required for *A. pyogenes* in the lumen of the uterus. Ceftiofur is a third-generation cephalosporin that has broad spectrum activity against gram-positive and gram-negative bacteria implicated in the cause of metritis (Chenault et al., 2004). Moreover, ceftiofur has been reported to reach all layers of the uterus without having violative residues in milk. Subcutaneous administration of ceftiofur at a dose of 1 mg/kg in dairy cows after parturition resulted in a concentration of ceftiofur and its active metabolites in plasma, uterine tissues, and lochial fluid that exceeded reported minimum inhibition concentration values for common pathogens involved in metritis (Schmitt & Bergwerff, 2000). Ceftiofur administered at a dosage of 2.2 mg/kg daily for 5 days is an equally effective treatment for postpartum dairy cows affected with metritis (rectal temperature >39.2°C [102.6°F], flaccid uterus, and a fetid vaginal discharge) when compared with procaine penicillin G or procaine penicillin G plus intrauterine infusion of oxytetracycline (Smith et al., 1998). In a multilocation study that involved 406 cows in the first 14 days postpartum, ceftiofur administered at a dosage of 2.2 mg/kg daily for 5 days was efficacious in the treatment of metritis (rectal temperature >39.5°C [103.1°F] with a fetid vaginal discharge) (Chenault et al., 2004). Ceftiofur is approved in the United States for systemic administration to lactating dairy cows affected with metritis. An advantage for the use of ceftiofur is that because there are no violative antibiotic residues in milk, treated cows do not have to be moved to the hospital pen, avoiding movement stress, and their milk does not have to be discarded.

Nonsteroidal anti-inflammatory drugs such as flunixin meglumine (1.1–2.2 mg/kg of body weight) can be used to treat fever. Furthermore, cows with metritis may experience depressed appetite affecting calcium and energy status. Consequently, therapy with calcium and energy supplements may be warranted.

A variety of hormones has been administered to cows in attempts to prevent or treat postpartum metritis. Clinical trials have shown that administration of prostaglandin during the postpartum period may enhance the reproductive performance of dairy cows that are otherwise unaffected by periparturient diseases (Young et al., 1986). Likewise, cows affected with dystocia, retained

fetal membranes, or both, and treated with prostaglandin F_2 alpha (PGF_{2a}) early postpartum, followed by a second treatment of PGF_{2a} 14 days later, experienced a higher conception rate to first service than did untreated cows experiencing a normal or abnormal parturition (Risco et al., 1994). In primiparous cows treated for puerperal metritis with systemic ceftiofur, the administration of two doses of PGF_{2a} 8 h apart, on day 8 postpartum, improved uterine involution, decreased the concentration of inflammatory products, and improved first service conception rate (Melendez et al., 2004).

Mastitis

Mastitis is an economically important disease of dairy cattle due to losses in milk production and replacement and treatment costs. In addition, clinical mastitis can affect reproductive performance by increasing the number of days to first service, days nonpregnant, and services per conception (Moore et al., 1991; Barker et al., 1998), together with a higher risk of abortion (Risco et al., 1999; Santos et al., 2004).

Gram-positive bacteria causing clinical mastitis may be associated with embryonic losses in dairy cows by stimulating the release of inflammatory mediators and pyrexia (Barker et al., 1998). Effects of these inflammatory mediators include alteration of luteinizing hormone (LH) release and follicle-stimulating (FSH) activity, which can alter oocyte development, estrous cycle, and embryonic function (Hansen et al., 2004). In contrast, endotoxin (lipopolysaccharide [LPS]) from gram-negative bacteria increased serum $PGF_{2\alpha}$ levels (Giri et al., 1984, 1990; Jackson et al., 1990) and, through its luteolytic action, altered the estrous cycle or caused abortion in cows (Gilbert et al., 1990).

Subclinical mastitis, defined as the presence of the same pathogen in at least two consecutive milk samples, resulted in lower reproductive performance of lactating cows, comparable to that of cows with clinical mastitis (Schrick et al., 2001). Furthermore, a negative effect of a linear somatic cell count (LNSCC) ≥4.5 on embryo survival was reported (Moore et al., 2005). Pinedo et al. (2009) evaluated the effect of high LNSCC (≥4.5) during early lactation on reproductive performance, and estimated their association with the risk of abortion in a population of central-southern Chilean dairy cattle. After controlling for significant variables, time to first breeding was 21.8 days longer in cows with at least one high LNSCC before the first breeding compared with controls. Cows with at least one high LNSCC before the fertile breeding had an increment in time to conception of 48.7 days and required on average 0.49 more services to conceive. The odds of conception at first service in cows with a high LNSCC within 30 days before breeding were lower than those for cows without a high LNSCC during that period. Cows registering a high LNSCC during the first 90 days of gestation had an increased risk of abortion and were 1.22 (1.07–1.35; 95% CI) times more likely to abort than nonaffected cows.

From these studies, it is clear that either clinical or subclinical mastitis has a significant effect on reproductive performance in dairy cattle. Therefore, veterinarians engaged in reproductive management of dairy farms should ensure that mastitis prevention practices are well-established if reproductive performance is expected to be optimized.

Embryonic Loss

A study that evaluated factors affecting embryonic loss in dairy cattle indicated that 39% of cows pregnant on day 23 lost their embryo by day 27, and 18% of cows that were pregnant on day 27 or 28 were not pregnant on days 35–41 (Moore et al., 2005). The greatest risk identified for embryonic loss during both periods was insemination of pregnant cows, low progesterone concentration, and cows with a linear somatic cell count ≥4.5. The authors concluded that veterinarians can play an important role in controlling embryonic loss by

- Ensuring proper training of insemination technicians to improve accuracy of estrus detection, that is, to reduce the breeding of cows that are pregnant but incorrectly identified as being in estrus.
- Working with producers to reduce the incidence of mastitis, which can cause reproductive losses.
- Monitoring BCS and evaluating rations to avoid prolonged postpartum negative energy balance that can affect progesterone concentration.

In addition to the risk factors for embryonic mortality discussed earlier, we must recognize that infectious causes of pregnancy loss can have a major economic impact on dairy farms. Worldwide, bovine viral diarrhea virus (BVDV) and *Leptospira* spp. are the two most common causes of infectious diseases associated with reproductive losses. These diseases have been associated with infertility, early embryonic deaths, and abortions. It is imperative that a reproductive program include a sound vaccination program to prevent reproductive losses from these diseases.

Lameness and Reproductive Performance

Due to its painful condition, lameness is an animal welfare concern and reduces reproductive performance in dairy cattle. Therefore, as part of their reproductive management programs, dairy farms should strive to

implement lameness prevention strategies with prophylactic hoof trimming.

Lameness delays resumption of cyclicity after calving and prolongs the calving to conception interval in dairy cows (Garbarino et al., 2004). In lame cows, the effect of lameness on time to conception is greater in cows with severe lameness compared with cows with mild lameness (Hernandez et al., 2007). Bicalho et al. (2007) evaluated the reproductive performance of cows according to lameness score in the first 70 DIM (1 = normal, 2 = presence of a slightly asymmetric gait, 3 = the cow clearly favors one or more limbs, 4 = severely lame, or 5 = non-weight-bearing in one or more limbs). Cows with a lameness score ≥3 were 15% less likely to be pregnant by 305 days postpartum than cows with a lameness score ≤2. Further, in cows with a lameness score ≥3, calving to conception interval was 149 days, compared with 119 days in cows with a lameness score ≤2. Lameness also changes normal cow behavior and compromises gait; the unwillingness to bear weight in one or more limbs inhibits estrual behavior, reducing detection of estrus in affected cows.

Prophylactic hoof trimming was reported to be beneficial by reducing the incidence of severe lameness (Hernandez et al., 2007). Healthy cows examined for foot lesions and hoof-trimmed around 200 days postpartum (prophylactic hoof trimming) tended to be less likely (18%) to be diagnosed lame thereafter than those that were not examined and not hoof-trimmed (no prophylactic hoof trimming, 24%). Cows not receiving prophylactic hoof trimming tended to be 1.25 times as likely to become lame compared with cows receiving prophylactic hoof trimming.

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11

Infectious Reproductive Diseases

Victor S. Cortese

Abstract

Reproductive disease caused by infectious agents is the hardest to protect against because during gestation, the bovine reproductive system, with its multilayered placenta (epitheliochorial), leaves the fetus in a naive environment susceptible to infection. Abortions may occur due to infection of the placenta, inflammation of the ovary, death of the fetus, and disruption of the cervical plug. The key to vaccination for infectious reproductive diseases is to minimize the amount and duration of the viremia, septicemia or prevent the infectious agent from moving through the cervix. This chapter discusses common infectious causes of reproductive diseases.

Introduction

During gestation, the bovine reproductive system, with its multilayered placenta (epitheliochorial), leaves the fetus in a naive environment susceptible to infection. Abortions may occur due to infection of the placenta, inflammation of the ovary, death of the fetus, and/or disruption of the cervical plug. Thus, infectious reproductive disease is the hardest to protect against. Vaccination must minimize the amount/duration of the viremia/septicemia or prevent disease from moving through the cervix.

Infectious reproductive diseases and protection against them through vaccination are areas of active research that allow for the establishment of a vaccination program to aid in the control of reproductive diseases. Unfortunately, there is little or no research regarding the reproductive efficacy of many vaccines currently used to prevent reproductive diseases. Due to the numerous causes of reproductive failures (of which infectious agents are a small percentage), vaccination to prevent infectious reproductive losses many not appear to be effective. This is often due to the fact that diagnostic testing has not been attempted or has not determined the cause of reproductive inefficiencies. A vaccination program may be inappropriately instituted when the cause is not infectious or the current program may be unfairly deemed ineffective. This chapter discusses common causes of infectious reproductive diseases.

Infectious Diseases for Which Reproductive Studies Have Been Performed

Bovine Viral Diarrhea Virus (BVDV)

BVDV is potentially the most lethal of common cattle viruses in young calves. It is also a ubiquitous and economically important viral pathogen of cattle in North America and other parts of the world (Cortese, 1991; Thiel et al., 1996; Houe, 1999).

Infection may be completely unapparent as is often seen in adult cattle or may cause a severe disease bordering on the appearance of mucosal disease (Bolin, 1990; Bolin & Ridpath, 1992). The one constant that appears with these infections is an immune suppression. The

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severity of disease as well as the severity of the immune suppression appears to be tied into the strain infecting the animal (Bolin, 1992; Bolin & Ridpath, 1992; Thiel et al., 1996; Houe, 1999). In most of these infections, if the animal is unexposed to other disease agents while undergoing the immune suppression, it will recover; however, if there is another disease agent present, the mortality and morbidity rates can be greatly elevated (Cravens & Bechtol, 1991; Donis, 1995; Thiel et al., 1996; Pollreisz et al., 1997; Penny et al., 2004; Daly & Neiger, 2008).

BVDV Classification

Two biotypes of BVDV, noncytopathic and cytopathic, exist in nature. The noncytopathic biotype is the most common and is characterized by failure to induce cytopathic effect in cultured cells. The rarer cytopathic viral biotype causes cell death in susceptible cell cultures, and usually is co-isolated with a noncytopathic BVDV from tissues of cattle showing signs of mucosal disease. The BVDV genome is a single strand of positive-sense RNA (Holland et al., 1982; Domingo et al., 1998). Similar to other RNA viruses, BVDV is capable of rapid mutation, which leads to many BVDV strains. Stable genetic variants of BVDV can be segregated into genotypes (large groups of genetically similar viruses, type 1 and type 2), which can be further divided into genogroups (a subtype of genetically related viruses within a genotype;1a, 1b, 2a, and 2b; Pellerin et al., 1994; Ridpath et al., 1994; Becher et al., 1997; Vilček et al., 2001). The type 1 versus type 2 designation does not correlate with virulence. There can be severe death loss with either division depending on the strain. The only group-specific disease is the thrombocytopenic form which is seen with only several type strains.

BVDV Reproductive Syndromes

Understanding the differences in reproductive syndromes caused by the cytopathic or noncytopathic strains are important because of what it may indicate in the herd. The cytopathic and noncytopathic strains react differently in the nonimmune pregnant cow. The noncytopathic strains tend to have a much higher affinity for the reproductive tract. If a nonimmune cow is exposed to a noncytopathic strain while in the first trimester of gestation, early embryonic death, abortion, mummification, or persistently infected (PI) calves can result. If exposure occurs during the second trimester, birth defects, primarily involving nervous tissue, or occasionally persistent infection, are found. Infection during the last trimester usually has no effect on the fetus, and the calf will be born with antibodies against bovine viral diarrhea (BVD). Rarely, an overwhelming exposure can cause a late-term abortion.

Bovine Herpesvirus (BHV) Type-1

Infectious bovine rhinotracheitis (IBR), also referred to as rednose, can spread easily through respiratory, ocular, and reproductive secretions from infected cattle. The virus remains in postinfected animals via latent infections of the trigeminal ganglia. Infections with BHV-1 cause severe respiratory tract infections with a 5%–10% death loss. Abortions due to exposure to BHV-1 are well recognized. Field exposure to BHV-1 can cause up to 25%–50% of the cows to abort (Miller, 1991). The majority of BHV-1 abortions are seen in the last trimester of pregnancy; however, abortions can occur at any stage of pregnancy. Expulsion of the fetus may be delayed up to 100 days after exposure to the virus. IBR abortions have occurred when suckling beef calves were exposed to BHV-1 or were vaccinated with a modified live BHV-1 vaccine and turned back with their nonimmune dams (Kelling et al., 1973). This problem should not be a concern, however, if the dams have been properly immunized. However, the impact of BHV1 on ovarian tissue and its impact on conception failure are being seen with an increasing frequency. Exposure of susceptible female cattle to BHV-1, either 3–4 days before breeding, or 14 days after breeding, will lower pregnancy rates by approximately 30% (Bruner, 1979; Miller & Van Der Maaten, 1984; Chiang et al., 1990) The mechanism is thought to involve follicular necrosis (Holland et al., 1982; Miller et al., 1989) and lytic infection of the developing corpus luteum (Miller & Van Der Maaten, 1986). The virus can cause a temporary infertility due to follicular necrosis. The decreased conception rate for the estrous cycle following this occurrence has been estimated to be at 30%–50% and can also be caused by the administration of modified live BHV-1 vaccines (Miller et al., 1989; Chiang et al., 1990). It has also been shown that the effect on the ovary is not seen in previously vaccinated heifers (Spire & Edwards, 1995; Bolton & Brister, 2007).

This virus can also cause conception failure as a venereal disease (infectious pustular vulvovaginitis). Pustular and necrotic lesions are seen on the vulva and vaginal tract, and a balanoposthitis can be seen in bulls. A mucopurulent discharge may be seen during the infection in cows. The disease is spread primarily by infected breeding bulls and occasionally by the sniffing habits of cattle.

Leptospirosis

Although usually associated with abortions, *Leptospira interrogans* and *Leptospira borgpetersenii* can also cause severe liver and/or kidney disease, vasculitis, and in some situations cause an outbreak of mastitis. Six *Leptospirae* have been shown to be primarily involved in clinical disease, reproductive failure, and abortions in cattle,

although any of the pathogenic strains can cause an incidental infection with corresponding disease: *L. interrogans* serovar hardjo-prajitno, *L. borgpetersenii* serovar hardjo (formerly known as *Leptospira interrogans* serovar hardjo-bovis), *L. interrogans* serovar pomona, *Leptospira kirschneri* serovar grippotyphosa, and *L. interrogans* serovar icterhaemorrhagiae. *L. borgpetersenii* serovar hardjo-bovis and *L. interogans* serovar hardjo-prajitno are the cattle-maintained serovars and account for the majority of cattle infections (White et al., 1982; Ellis & Thiermann, 1986). *L. interrogans* serovar pomona is maintained in pigs and other mammals and is the second most common *Leptospira* diagnosed in cattle. Cattle *Leptospira* has been shown to be zoonotic.

These bacteria can cause abortion storms in which high numbers of cattle may abort within a short period of time. There may be increased numbers of still births and birth of premature and weak calves. While serovar pomona tends to cause abortions in the last trimester of pregnancy, both serovars of hardjo can cause abortions at any stage of pregnancy. Abortions are usually due to fetal infections and subsequent death of the fetus. Furthermore, *L. borgpetersenii* serovar hardjo-bovis has been primarily associated with conception failure/early embryonic death (Dhaliwal et al., 1996). This is partially due to the ability of this *Leptospira* to colonize the oviducts, causing a decrease in fertility as well. After an initial *Leptospira* infection, cattle may remain infected and shed the spirochete for long periods of time (Ellis & Thiermann, 1986; Bolin, 1992; Ellis, 1994). Vaccination with *Leptospira* vaccines with reproductive challenge studies should be chosen when available.

Brucella abortus

Brucella vaccination has been the best to show effectiveness of vaccination in controlling a reproductive disease. The successful control and eradication of *Brucella abortus* from many areas in North America are a testament to the ability of a program involving testing and culling and vaccination can control a reproductive disease (Nicoletti, 1986). Vaccination with either strain 19 or RB51 Brucella have been shown to be effective; however, many herds have stopped vaccinating against this disease as states have been declared Brucella free.

Abortions due to *B. abortus* are seen usually after 5 months of gestation. Retained placentas and subsequent metritis usually follow this. The abortion is caused by severe placentitis. Brucella infections have also been associated with decreased conception rates and increased services per conception. Increased numbers of dead and weak calves have also been demonstrated in infected herds. Orchiditis and/or seminal vesiculitis may characterize infections in bulls (Nicoletti, 1986)

Only heifer calves can be vaccinated for brucellosis. Both of the licensed *B. abortus* vaccines are modified live bacterins, and vaccination of bulls may lead to orchiditis (Lambert et al., 1964). Its legal use is usually confined to heifer calves between the ages of 4 and 12 months since the vaccination of older animals with the strain 19 vaccine may lead to false positives on routine Brucella screening tests. Since the strain 19 vaccine may cause septicemia, clinical illness, and occasional deaths, vaccination of sick, unhealthy, or stressed cattle should be avoided (Roberts et al., 1962). The RB51 is an O-antigen-deficient mutant of the *B. abortus* strain 2308. It has three primary advantages: (Confer et al., 1985)

1. Antibodies induced by this vaccine do not react with the serologic tests routinely run to diagnose Brucella infections.
2. It can be used in adult cattle, at a lower dosage, under special circumstances and permission of the United States Department of Agriculture.
3. It tends to cause less postvaccination fevers and stress than the traditional strain 19 vaccines.

The long-term immunity conferred by Brucella vaccine is of the cell-mediated type. Calfhood vaccination will not prevent a herd of cattle from becoming infected with *B. abortus.* It will, however, largely prevent abortions and protect 65%–75% of the cattle in the herd from infection while infected reactors are being identified and slaughtered. Thus, a control program should include vaccination and testing and culling of all positive animals.

Bovine Trichomoniasis

Bovine Trichomoniasis is a venereal infection of cattle caused by the protozoal agent *Tritrichomonas fetus*. Early in an infection, abortions with pyometra may be seen in 5% of the cows. These abortions occur early in gestation. However, infertility is the most common sign, with long interservice intervals. Early embryonic death is followed by a period of conception failure. There is some natural resistance after infection, but carrier cows may be an important component of the epidemiology of this disease. Rarely, a cow may become sterile following an infection due to uterine destruction. Efficacy of *Tritrichomonas* vaccines is questionable and is estimated to be at best 60% (Dawson, 1986).

Bovine Genital Campylobacteriosis

Originally classified as Vibrio, *Campylobacter fetus* subspecies venerialis causes a venereal infection of cattle. The bacteria are introduced during natural breeding by infected bulls or by artificial insemination using infected semen. Bulls are usually infected by servicing infected cows, but contact with infected bedding may also cause

infection to occur. Older bulls (>4 years of age) are more likely to be infected. After depositing in the vagina, the bacteria rapidly colonize the vagina and cervix and in 25% of the cows, will be found in the oviducts. It can persist for months after infection in these sites (Hoerlein & Carroll, 1970).

Early embryonic death and prolonged estrus cycles are the most common signs in *Campylobacter*-infected cows. Early abortions may be seen as well. The signs are much higher in heifers, with immunity developing after a 4- to 6-month cycle with the infection. It has been shown that fertility will never return to normal in some infected animals, and some animals may be permanently sterile due to the damage after salpingitis (DeKeyser, 1986; Hoerlein, 1986).

Vaccination with *Campylobacter* vaccines has been shown to be effective in protecting heifers even when vaginal cultures are positive for the bacteria (Hoerlein & Carroll, 1970). This is felt to be due to the fact that the uterus is very resistant to the bacteria after vaccination. Studies have demonstrated improved breeding efficiency in vaccinated herd (Berg & Firehammer, 1978). Furthermore, vaccination with two doses has been shown to be effective at clearing infections from carrier bulls (Bouters et al., 1973; Clark et al., 1975).

Reproductive Diseases Lacking Vaccine Efficacy Studies

Neospora caninum

Neospora caninum abortions in cattle are relatively common and are economically important (Paré et al., 1998). Canids are the primary hosts (McAllister et al., 1998; Gondim et al., 2004) and can shed the eggs in their feces after ingestion of an intermediate host (Gondim et al., 2002). The role of other wildlife vectors is unclear (Gondim, 2006). Abortions, usually second trimester, birth defects, and early embryonic death loss have all been attributed to *Neospora* infections. An infected dam may transmit the infection to her offspring; however, cow-to-cow transmission has not been documented. Cows that abort due to the *Neospora* are not immune to subsequent infections and often will abort repeatedly (Dubey et al., 2006). In herds with a high prevalence of *Neospora*-associated problems, an underlying immune suppression may be involved.

Salmonella

Many different *Salmonella* strains have been isolated from aborted fetuses of cattle. The abortion may be due to placentitis, endotoxin-induced luteal lysis, or fetal death (Hall & Jones, 1977; East, 1983; Hinton, 1986). Early embryonic loss, abortions, stillbirths, and neonatal septicemia have all been attributed to *Salmonella* infections. Diarrhea in the dam may precede the abortion, and often, retained fetal membranes are seen following a late-term abortion; however, often the cow is asymptomatic. Expulsion of the fetus is usually seen 1–4 weeks after infection in the dam.

The infection usually occurs by ingestion of contaminated feed or water. Infected animals may be short-term shedders although lifetime asymptomatic carriers may be seen with *Salmonella dublin* (host-adapted strain), and even long-term carriers of non-host-adapted serotypes have been identified (usually intestinal). Maternal septicemia leads to localized infections in a number of tissues including the uterus. Necrosis of the cotyledons and/or fetal septicemia may occur. If endotoxin is the cause of the abortion due to prostaglandin release, the fetus is often negative for *Salmonella* on culture. *Salmonella dublin* and *Salmonella typhimurium* are the two most commonly isolated serotypes from bovine abortions.

Histophilus somnis

The name *Haemophilus somnus* was recently changed to *Histophilus somni*, which we will use in this discussion. *H. somni* is the cause of thrombotic meningoencephalitis (TME), septicemia, and reproductive disorders in cattle. In addition, it is the third most common bacterial isolate from beef cattle pneumonia in most epidemiological surveys. *H. somnis* can be isolated from the reproductive tract of females following early abortions as cows carrying normal pregnancies. It is believed that *H. somni* is a normal inhabitant of the vaginal tract of cattle.

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12

Economics of Reproductive Performance

Albert De Vries

Abstract

Reproduction provides the next generation of females and initiates milk production after calving. Reproductive performance in dairy cattle declined for at least 40 years while milk production increased. Timed artificial insemination (timed AI) programs are popular in the United States, in addition to AI based on estrus detection and the use of natural service bulls. Timed AI programs are typically profitable compared with programs based on estrus detection in both heifers and cows. An increase in pregnancy rate from 16% to 17% is worth approximately $18 per cow per year, with a greater marginal value when pregnancy rate is lower. The cost of an extra day nonpregnant may be $2.50, with a lower cost early in lactation and a greater cost later in lactation. The optimum interval from calving to conception is approximately 133 days for first parity cows and 2–3 weeks shorter for later parity cows. First inseminations should be approximately 5 weeks before the optimum time of conception. The average value of a new pregnancy, $278, is also lower early in lactation and peaks around the middle of lactation. Abortion costs on average are $555, with greater cost later in gestation and later in lactation. The economics of reproductive performance are farm- and animal-dependent.

Introduction

Reproduction is necessary to provide the next generation of females and to initiate milk production after calving, which is the primary source of income on dairy farms. Many factors affect the economics of reproductive performance in dairy cattle. Important factors are the purchase or raising cost of dairy heifers, cull rates, shapes of lactation curves, genetic progress, insemination and conception rates, insemination and replacement policy, prices for milk, culled cows and calves, as well as of costs of feed, labor, and the reproductive program. The number of days nonpregnant may affect milk production and culling risk in the next parity. In addition, herd demographics need to be considered. For example, increased culling due to reproductive failure will lead to more first parity cows in the herd with their own performance characteristics. Improved reproductive performance will lead to a greater portion of cows that are dry. Accurate economic analyses that consider these factors are necessarily complex. This chapter discusses the status of dairy cattle reproductive performance in the United States. It further provides estimates for the value of improved reproductive performance, optimum days to first insemination and conception, cost per day open, and the value of pregnancy and insemination.

Brief Overview of Current Reproductive Performance and Breeding Programs

Reproductive performance in dairy cattle decreased in the United States for at least 40 years until approximately 2002 when stabilization occurred (United States Department of Agriculture, 2010). Washburn et al.

Dairy Production Medicine, First Edition. Edited by Carlos A. Risco, Pedro Melendez Retamal.

(2002) reported an average of 124 days nonpregnant for Holstein herds in the Southeastern United States in 1977 to 168 days in 1998. They also reported increased services per conception, and days to first service increased. Estrus detection rates generally declined from 1985 to 1999. De Vries and Risco (2005) reported a decrease in pregnancy rates, measured as the number of conceptions per nonpregnant eligible cow every 21 days, of 44% between 1978 and 2002 in Holstein herds in Florida and Georgia. Pregnancy rates in the early stages after calving showed greater decreases than pregnancy rates in the later stages. Pregnancy rate is considered to be the key reproductive performance indicator. Decreases in reproductive performance have also been reported elsewhere in the United States, Europe, and Australia (Lucy, 2001), but exceptions exist (Refsdal, 2007).

Average dairy statistics based on 12,311 Holstein herds located primarily in the Eastern United States are shown in Table 12.1. Variation in reproductive performance among dairy farms is large. Figure 12.1 shows the distribution of current pregnancy rates just before March 9, 2010. The average current pregnancy rate is 17.1% because reproductive performance is better in the winter than in the summer.

Slightly more than half of all dairy farms use artificial insemination (AI) to natural estrus as the first insemination breeding practice (United States Department of Agriculture, 2009). Natural service bulls are widely used throughout the United States (Smith et al., 2004; De Vries et al., 2005; and Caraviello et al., 2006). The United States Department of Agriculture (2007) reported that 51% of all operations used at least one bull for breeding dairy cows or heifers. In the Southeastern United States, De Vries et al. (2005) estimated that 70% of Dairy Herd Information Association (DHIA) herds used bulls as a component of their breeding program. The United States Department of Agriculture (2009) reported that bulls were used for the first insemination by one-third of the surveyed dairy farms for heifers and one-fifth of dairy farms for cows.

Table 12.1. Some dairy statistics based on 12,311 Holstein herds located primarily in the eastern United States. Statistics compiled on March 9, 2010 by DRMS, Raleigh, NC

Statistic	Value
Herd size (cows)	155
Days in milk	184
Age at first calving (months)	26
Annual cull rate (%)	35
Rolling annual milk yield (kg)	9577
Milk fat (%)	3.8
Milk protein (%)	3.1
Somatic cell count (x 1000)	287
Voluntary waiting period (days)	58
Estrus detection rate (%)	43
Days to first insemination	95
First insemination conception rate (%)	43
Inseminations per pregnancy	2.9
Pregnancy rate (%)	15.6
Projected minimum days open	158
Actual calving interval (months)	14.1

Source: DRMS (2010).

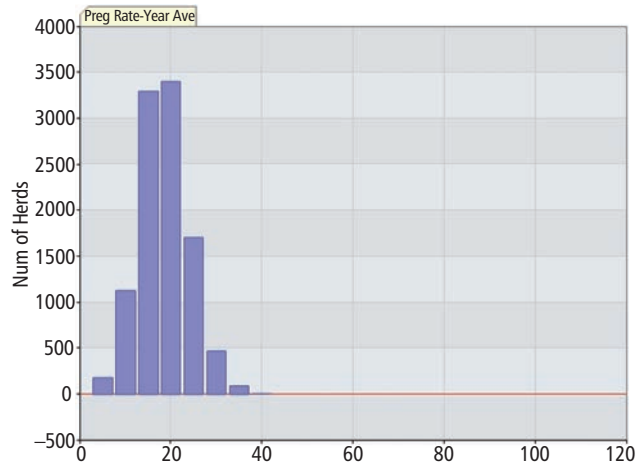

Figure 12.1. Distribution of current pregnancy rates reported by DRMS (2010) for 12,311 Holstein herds located primarily in the eastern United States. Data compiled on March 9, 2010.

Ovulation synchronization using hormones followed by timed AI remains popular among U.S. dairy producers. The United States Department of Agriculture (2009) reported that 3% of all dairy farms used timed AI for first insemination in heifers and 16% in cows. About 58% of dairy farms used timed AI programs for at least some cows during the previous 12 months and about 25% used timed AI programs for at least some heifers. Timed AI programs were used for either heifers or cows on 58% of dairy farms. Half of dairy farms reported that timed AI programs were used occasionally to catch up on nonpregnant cows. Many dairy farms use a mixture of timed AI, AI based on natural estrus, and natural service.

Comparisons of Reproductive Programs

Because a large variety of breeding programs are being used, a common question is which program is the most profitable. Generally, the most suitable program depends on the management capabilities of the dairy farm and the interest of the manager.

Lima et al. (2010) compared the economics of timed AI and natural service bulls using actual farm data. Both breeding programs were directly compared in a field study on a large dairy farm in Florida. Net expenses for the bull program during the field study was $100/cow/year and $67/cow/year was spent for the timed AI program, unadjusted for differences in voluntary waiting period for first insemination (70 for bulls, 80 for timed AI) and pregnancy rates (25.7% for bulls and 25.0% for timed AI). After inclusion of the effects of the different pregnancy rates on herd demographics, the economic advantage of the timed AI program was $10/cow per year. Feed costs for bulls, semen price, and genetic merit of semen, as well as the opportunity cost of replacing bulls with cows in the same pen, were major factors.

Other studies have used simulation to compare profitability of reproductive programs. For example, LeBlanc (2007) reported an increase of $30/cow per year when a timed AI program was implemented compared to a program based on estrus detection for a Canadian herd. De Vries and Galligan (2009) compared the economics of timed AI programs and AI based on natural estrus detection in heifers and cows. Timed AI programs typically resulted in lower cost per pregnancy than AI programs based on natural estrus. For heifers, average cost per pregnancy was $167 when estrus detection rate was 70%. The cost per pregnancy with a timed AI program ranged from $128 for only the first insemination with timed AI, to $163 when the first four inseminations were with timed AI. Attributes of the timed AI program (days to timed AI, conception rate, cost of labor, drugs and semen, and time to next insemination) had a major effect on the cost per pregnancy. For cows, the average cost per pregnancy with AI and natural estrus detection was $318. The cost per pregnancy with timed AI programs ranged from $170 to $238.

Economic Value of Improved Reproductive Performance

Realistic economic benefits of improved reproductive performance are not simple to obtain. When reproductive performance improves, all changes in cash flows that result from the improvement must be accounted for. For a good analysis, at least realistic estimates of milk production curves, feed intake, the risk of culling, and prices such as for milk, feed, labor, semen, possibly reproductive hormones, calves, replacement heifers, and cull cows are needed.

De Vries (2004, 2006) used an economic modeling computer program (dairy value iteration program [DairyVIP]) to evaluate the economic benefits of changes in reproductive performance. DairyVIP first calculates optimal breeding and replacement decisions for individual dairy cows (using the dynamic programming method) and then calculates many technical and financial herd statistics for a herd of dairy cows that are managed following the calculated breeding and replacement decisions (using the Markov chain method).

In the default situation, key assumptions were a milk price of $40/100 kg, a calf price of $300, a cull price of $90/100 kg of body weight, and a heifer price of $2000. Body weight and feed intake were taken from the 2001 NRC recommendations (National Research Council, 2001). The default situation also assumed a 55% 21-day service rate and a conception risk that peaked at 37% on day 91 after calving and then gradually declined to 23% on day 456. The relative risk of conception declined from 100% in first parity cows to 78% in eighth parity cows or older. The risk of abortion during the gestation after the first month of pregnancy was 8.2%. Breeding cost was $20. Open cows were eligible to be bred up to 456 days in milk (15 months) if not involuntary or voluntary culled earlier in lactation. Minimum voluntary waiting period was 60 days, but DairyVIP may decide to postpone breeding of some cows if that is economically advantageous. Labor time spent and cost depended on the time from calving and whether the cow was milking or dry. Veterinary costs were $38 per cow in the first month after calving and declined to $1 per month after 4 months after calving. Milk production curves for average first parity cows peaked at 36.6 kg/day on day 137 after calving. Total 305-day milk yield was 10,055 kg. Average second parity cows peaked at 45.0 kg/day on day 76 with 11,844 kg in 305 days. Average third and later parity cows peaked also at 76 days but with 47.5 kg and with 12,408 kg in 305 days. Thus, milk production curves for first parity cows peaked later, were lower, and were more persistent than those for older cows. Milk production was reduced by 5%, 10%, and 15% for months 5–7 of gestation. The length of the dry period was 2 months (last 2 months of gestation). Individual cows varied their milk production from 70% to 130% from the average milk production.

Although DairyVIP optimized voluntary replacement and breeding decisions, every cow was still at risk for involuntary culling (essentially, a risk for a change in nature that made immediate culling unavoidable). The basic risk of involuntary culling declined from 2.6% in the first month after calving to 0.9% per month from approximately day 137 to day 350 after calving. After day 350, the risk increased again. The relative risk of involuntary culling increased with parity, from 100% of the basic risk for first parity cows to 552% for cows in their eighth or later parity.

Table 12.2. Herd statistics in the default situation calculated with DairyVIP (De Vries, 2006)

Variable	Per cow per year	Per 100 kg	Variable	
Milk sales ($)	4646	40.00	Days to first insemation	76
Cow sales ($)	186	1.60	Days to conception	143
Calf sales ($)	311	2.68	Days to last insemination	303
Total revenue ($)	5143	44.28	Calving interval (months)	13.7
Feed cost ($)	1954	16.82	Pregnancy rate	18%
Breeding supply cost ($)	55	0.47	Overall cull rate	34%
Heifer purchase cost ($)	682	5.88	Involuntary cull rate	24%
Veterinary cost ($)	79	0.68	Voluntary cull rate	10%
Variable labor cost ($)	402	3.46	Milk/cow/year (kg)	11,614
Variable other cost ($)	343	2.95	Total cost/pregnancy ($)	62
Fixed cost ($)	1095	9.42	Value of new pregnancy ($)	284
Total costs ($)	4609	39.69	Cull price ($)	545
Profit ($)	534	4.60	Income over feed cost ($/day)	7.38

Table 12.3. Effect of pregnancy rate on selected herd statistics under the default assumptions calculated with DairyVIP (De Vries, 2006)

Herd statistic	Pregnancy rate							
	7%	10%	14%	18%	22%	27%	32%	38%
21-Day service rate	40%	45%	50%	55%	60%	65%	70%	75%
Conception rate	18%	23%	28%	32%	37%	41%	46%	50%
% Cows in parity 1	52	44	39	36	34	33	32	31
% Cows in parity 2	28	28	27	27	26	25	25	25
% Cows lactating	92	90	89	88	88	87	87	86
Milk yield lactating cows (kg/day)	34.5	35.2	35.7	36.1	36.5	36.7	36.9	37.1
Milk yield all cows (kg/day)	31.6	31.7	31.8	31.8	31.9	32.0	32.0	32.1
Average days in milk	232	234	233	231	229	226	224	222
Annual cull rate (%)	48	41	37	34	32	31	31	30
Days to conception	172	162	152	143	136	130	124	120
Value of new pregnancy ($)	646	494	375	284	216	166	128	102
Breeding cost per pregnancy ($)	110	87	73	62	54	48	44	40
Milk sales ($/cow/year)	4614	4626	4635	4646	4656	4666	4673	4680
Cow sales ($/cow/year)	260	225	201	186	176	170	167	164
Calf sales ($/cow/year)	293	299	305	311	316	321	325	328
Feed cost ($/cow/year)	1957	1957	1955	1954	1953	1953	1952	1952
Heifer purchase cost ($/cow/year)	958	825	737	682	647	627	614	606
Profit ($/cow/year)	255	380	469	534	580	614	640	658

With the default inputs, Table 12.2 shows the resulting cost and revenues per cow per year and per 100 kg of milk and some other herd statistics. Breeding supply costs include the cost of semen only. These results are in agreement with results that could be expected on reasonably progressive dairy farms in the United States. Together, they lend credibility to the set of chosen default assumptions.

Economic Value of a Change in Pregnancy Rate

DairyVIP was used to evaluate the economic effects of a change in pregnancy rate. To do so, 21-day service rate and conception rate were simultaneously varied from −15 percentage points to +20 percentage points with increments of 5 percentage points. This resulted in pregnancy rates from 7% to 38%. Table 12.3 shows some

selected herd statistics for various pregnancy rates. Increasing pregnancy rates lead to fewer cows in parities 1 and 2 and a lower cull rate. This trend can be seen in reduced cow sales and reduced heifer purchase costs. A greater pregnancy rate resulted in shorter lactations as can be seen by more milk per lactating cow, and fewer cows lactating. Collectively, milk sales did not increase very much because the increase in milk per lactating cow was offset by fewer cows lactating because cows were more often dry. Feed costs did not vary much. Profit per cow per year increased from $255 to $658 with greater pregnancy rate, but the rate of increase declined. Average days not pregnant decreased from 172 to 111.

The value of a marginal increase in pregnancy rate, that is, from 15% to 16%, is the change of profit per cow per year when pregnancy rate changes one percentage unit. Figure 12.2 shows that the marginal value is more than $40/cow/year in herds with low pregnancy rates to less than $5/cow/year in herds with greater than 30% pregnancy rates. For the average pregnancy rate in the United States, which is approximately 16%, the marginal value under the default assumptions is $16.41. When there is a cost associated with improving pregnancy rate, these marginal values will be smaller.

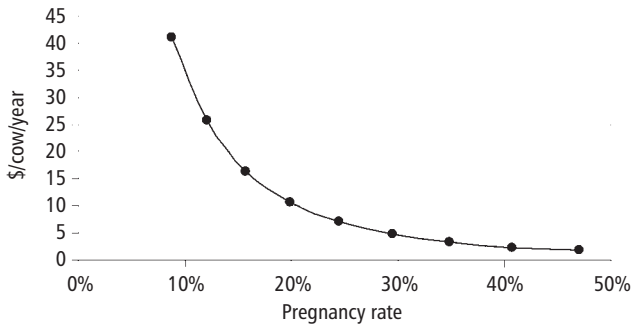

Figure 12.2. Effect of marginal, one percentage unit, change in pregnancy rate (e.g., from 15% to 16%) on profit per cow per year calculated with DairyVIP (De Vries, 2006).

Early after the improvement, heifer purchase costs are reduced because fewer cows are culled for failure to get pregnant. After the initial extra calves are born, starting 9 months after the implemented improvement, milk sales increase as well. The increase in profit per cow then is approximately $3–$4/month. After approximately 4 years, the herd has reached steady state again at the higher conception risk level.

Increases in conception rates during short stages of lactation, for example, during the first month of the eligible breeding period, results in small increases in overall herd pregnancy rate and profit per cow per year as shown in Table 12.4. In this example, the conception rate was increased by 5 percentage points during 30-day intervals in various stages of the lactation. The change in profit per cow per year was the greatest ($5.23 compared to the default scenario) when conception rate in days 91–121 was increased. On average, a cow had a 56% chance that she was bred between days 91 and 121. The probability of breeding later in lactation decreased because a cow was less likely to still be nonpregnant. Profit per breeding increased later in lactation. Therefore, although improvement in reproductive efficiency early in lactation was more profitable for the herd, improvement in reproductive efficiency later in lactation was more profitable per open cow that was bred later in lactation.

Variations in inputs lead to different values of a marginal change in pregnancy rate as is seen in Table 12.5. Especially, a marginal increase in pregnancy rate is worth more when the heifer price is high or cows are given fewer breeding opportunities. Both effects illustrate the importance of culling on the value of a marginal change in pregnancy rate. Increases in milk price and herd milk production have smaller effects.

Table 12.4. Effect of a five percentage point increase in conception risk during short stages of lactation calculated with DairyVIP (De Vries, 2006)

Stage of lactation	Herd pregnancy rate	Change in profit ($/cow/year)	Probability cow is bred in stage of lactation	Change in profit per breeding ($/year)
Default	17.7%	0.00	—	—
Days 61–90	18.2%	4.16	59%	6.99
Days 91–121	18.2%	5.23	56%	9.38
Days 122–151	18.1%	4.84	41%	11.69
Days 152–181	18.0%	4.40	31%	14.34
Days 182–212	17.9%	3.90	23%	16.78
Days 213–243	17.9%	3.28	18%	18.50
Days 243–273	17.8%	2.69	14%	19.79

Table 12.5. Effects of variations in some inputs on the value of a marginal change in pregnancy rate

Inputs	Pregnancy rate							
	9%	12%	16%	20%	24%	29%	35%	41%
Default	41.00	25.69	16.41	10.69	7.11	4.82	3.36	2.37
Heifer price $2400	49.59	30.44	19.00	12.13	7.93	5.28	3.55	2.53
Heifer price $1600	31.46	20.30	13.35	8.95	6.11	4.21	3.01	2.18
Milk price $34/100 kg	40.39	25.20	15.91	10.28	6.84	4.61	3.15	2.27
Milk price $46/100 kg	41.12	25.98	16.77	11.03	7.36	5.03	3.51	2.45
Max. 8 months breeding	45.39	33.48	23.48	16.02	10.55	7.03	4.85	3.38
Max. 12 months breeding	42.42	27.35	17.34	11.35	7.54	5.10	3.53	2.51
Milk yield +30%	41.00	26.18	16.95	11.31	7.49	5.11	3.58	2.55
Inv. cull rate –30%	44.03	27.62	17.72	11.62	7.77	5.30	3.67	2.66
Inv. cull rate +30%	38.36	24.25	15.40	9.98	6.63	4.47	3.09	2.17

Other studies looked at the value of a marginal increase in estrus detection rate, conception risk, or pregnancy rate. Marsh et al. (1987) found the value of a one percentage point increase in estrus detection rate (e.g., from 40% to 41%) to range from $1.15 to $1.66 and the value of a one percentage point increase in conception risk to be from $1.92 to $2.61/cow/year using four different culling and rebreeding policies (1987 U.S. dollars). Pecsok et al. (1994) reported that the value of a one percentage point increase in pregnancy rate was worth about $0.86 per cow per year when pregnancy rate was approximately 45% (1994 U.S. dollars). At a lower pregnancy rate (13%), a one percentage point increase was worth approximately $16.60. A decrease in the value of a marginal increase in pregnancy rate at higher pregnancy rates was also found by Risco et al. (1998) for seasonal conditions in Florida. They found no economic benefits from increasing pregnancy rate above 45%. Plaizier et al. (1998) reviewed the literature and found that values of a one percentage point increase in estrus detection rate had been estimated from a loss of $2 to a gain of more than $16 (1998 U.S. dollars). Their results also showed that improving poor reproductive performance was more valuable than improving already good reproductive performance. Collectively, the literature shows that the economic value of an improvement in reproductive efficiency is greater when reproductive efficiency is low.

In most of the United States, milk production and reproductive efficiency are reduced in the summer months which are hot and sometimes humid. For example, in Florida, milk production may decrease by 25% in the summer whereas pregnancy rate can decrease by 50% compared to the winter. Consequently, much effort is focused on improving reproductive efficiency in the summer.

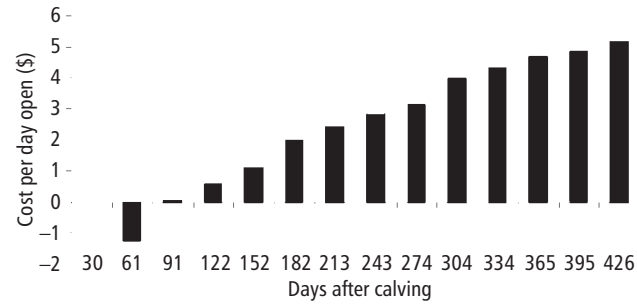

Figure 12.3. Herd average cost per day open by day after calving for the default situation.

Bell et al. (2009) reported that increases in first insemination conception rate were more profitable during the cooler season when basic conception rates were already greater than in the hot season. Again such improvement would result in a more seasonal herd with the majority of conceptions occurring in the cooler season. Despite the advantage of the cooler season for fertility, cows culled in the summer should typically be replaced as soon as possible (De Vries, 2004). Delayed replacement could be economically advantageous when fixed costs and net returns per slot are low and seasonality is high.

Cost per Day Not Pregnant

The average cost per day not pregnant per month after calving for the default inputs is shown in Figure 12.3. The negative cost per day not pregnant on day 61 illustrates that on average, the optimal day to conception is not yet reached: a day later pregnancy would actually

increase profitability. Differences in the actual cost per day open are largely influenced by the culling policy.

Plaizier et al. (1997) reviewed the literature and found the average cost of one additional day not pregnant to range from −$0.29 to $2.60. Their own estimate was a cost of approximately $3.36/extra day (1997 U.S. dollars). French and Nebel (2003) estimated the cost of an additional day not pregnant from $0.42 at 100 days open to $4.95 at 175 days not pregnant (2003 U.S. dollars). Meadows et al. (2005) estimated a loss of $0.44/cow/year for a 1-day increase in days not pregnant at 130 days and $1.71 for a 1-day increase at 190 days not pregnant (2005 U.S. dollars). LeBlanc (2007) used Groenendaal's model (Groenendaal et al., 2004) with inputs intended to reflect a Canadian herd and reported average cost per day not pregnant of $1.50, $2.10, and $2.50 at 90, 150, and 210 days, respectively, after calving. LeBlanc (2007) also reported cost per days not pregnant estimates adapted from Overton (2006) as $0.60, $2.10, $3.25, and $3.60 at 100, 150, 210, and 250 days, respectively, after calving.

These analyses do not include an effect of later conception on the risk of death and live culling around subsequent calving. Pinedo & De Vries (2010) reported that the risk of death and live culling in the first 60 days around subsequent calving increased from 2.5% to 5.8% when days open increased from less than 90 to greater than 300 days. The risk of live culling increased from 5.0% to 8.1% for the same periods. The risk of culling for cows who failed to get pregnant increased sharply after 250 days after calving (De Vries et al., 2010).

Figure 12.4 shows the economic loss caused by conception earlier or later after calving compared to the optimal day of conception for first parity cows for a slightly different set of default assumptions as described earlier (De Vries, 2008). The optimal day of conception is reached when the economic loss is $0 (bottom of the curve). The optimal day of conception for average first lactation cows was 133 days while for second and third lactation cows, it was 112 and 105 days, respectively. For lower producing cows, fewer days to conception were optimal. Similarly, for higher producing cows, greater days to conception were optimal.

The economic loss from a later day of conception (conception was too late) was smaller in first parity cows than in second parity cows. This is primarily caused by the much flatter lactation curve of first parity cows. This trend is in agreement with Holmann et al. (1984) who found that profitability was not affected very much when calving interval was either somewhat shorter or longer than 13 months (115 days to conception). Historically, the optimal calving interval has been 12–13 months (Stevenson, 2004), which is 90–120 days to conception.

The slopes of the curves shown in Figure 12.5 can be used to estimate the cost per extra day not pregnant for individual cows. As is expected, cost per extra day not pregnant is negative (a financial gain) before the optimal days of conception and positive (a financial loss) after the optimal day of conception. At day 150 after calving, cost per extra day not pregnant was $0.38 for first lactation cows and $1.17 for second lactation cows. At day 250, these costs had increased to $2.67 and $3.56, respectively. The cost per extra day not pregnant typically increases with days after calving and can be over $6 for individual cows late in lactation. These trends are similar to the cost per day not pregnant calculated based on changing herd average days open.

Different assumptions about conception rates, prices, milk production, or seasonality affect the optimal days to conception and cost of a day not pregnant and is shown in Table 12.6. Notice that the minimum time step of the computer program is 7 days. The 15% difference in milk production has more effect on optimal days to conception in first parity cows than in second parity cows. The effects of variations in maximum conception

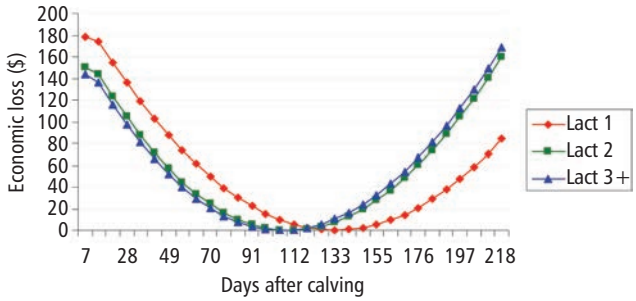

Figure 12.4. Economic loss ($/cow) caused by conception earlier or later after calving compared to the optimal day of conception. The optimum days of conception were 133, 112, and 105 for first, second, and third lactations, respectively.

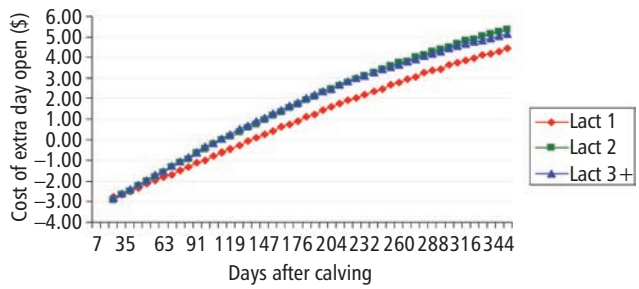

Figure 12.5. Cost per extra day open by day after calving and parity. Cost per extra day open is $0 at the optimum day of conception.

Table 12.6. Effects of various assumptions on the optimal days to conception for first and second parity cows by level of milk yield[1]

	Optimal days to conception					
	Parity 1			Parity 2		
Assumptions	–15%	Average	+15%	–15%	Average	+15%
Default[2]	91	133	169	77	112	140
Max. 25% conception risk	98	140	176	84	119	147
$0.46/kg milk price	91	133	176	77	112	140
$2500 heifer price	98	140	176	84	119	140
+15% herd milk yield	84	133	169	77	112	140
Less persistency[3]	63	105	133	56	91	112

[1] Average lactation curve, +15% and –15% compared to the average daily milk yield.
[2] Default assumptions: $2000 heifer price, $0.40/kg milk price, maximum 35% conception rate.
[3] Less persistency: faster reduction in daily milk production after the peak milk yield.

rates, milk price, heifer price, and herd level of milk yield were minor. When milk production in the herd was less persistent, optimum days to conception was earlier.

In areas with summer heat stress, milk production and conception risk are reduced during the summer. Such seasonality in cow performance has a large effect on optimal days to conception. Conception in the late summer is avoided, either by a short interval from calving to conception or a long interval from calving to conception. Thus, January calvings have shorter optimal days to conception, and July calvings have longer days to conception. Much of the effect of seasonality on optimal days to conception is triggered by a reduction in peak milk production in the summer compared to the winter. Therefore, it is not only the reduction in fertility that affects the optimal days to conception, but just as important is the reduction in milk production in the summer. These results also confirm delayed breeding practices of many dairy producers in areas with summer heat stress. Obviously, the effect of seasonality depends on the variation in heat stress throughout the year.

Value of a New Pregnancy

Figure 12.6 shows values of a new pregnancy by days after calving for the first three lactations for the default assumptions. The value of a new pregnancy increases during the course of the lactation until late in lactation when it starts to decrease again. For cows that differ in individual milk production, the value of a new pregnancy is greater for low-producing cows early in lactation, but their peak value is lower and earlier than higher producing cows.

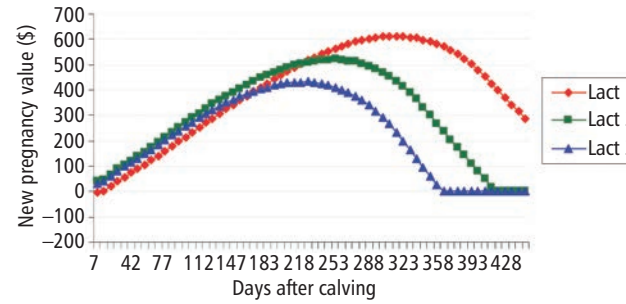

Figure 12.6. Value of a new pregnancy by days after calving and parity.

The values in Table 12.7 (De Vries, 2006) are slightly different from those reported in Figure 12.5 because of different inputs, but the trends are similar. Table 12.7 shows the differences in total discounted future revenues and costs that determine the value of a new pregnancy for 12 cows categorized by parity, days in milk at conception, and relative milk yield. For example, a cow in the first parity with 80% of the milk yield of the average lactation curve which conceived at day 61, and her replacement heifers, had $106 lower milk sales, $133 lower replacement costs, $31 lower feed costs, $27 lower breeding costs, and $1 lower other cost than an identical open cow. Calf sales were $34 greater than for open cows. Total revenues were reduced by $72, and total costs were reduced by $192. Therefore, the value of the new pregnancy was $120.

Table 12.7. The value of a new pregnancy ($U.S.) explained by differences in the sums of discounted future revenues and costs of a newly pregnant cow (pregn.) compared to an identical open cow (open)

						Differences in sums of discounted future revenues and costs ($): Pregnant−open					
Lact. no	Day at conception	Milk yield (%)[1]	RPO pregn.	RPO open	Value of new pregnancy[2]	Milk sales	Calf sales	Repl. costs[3]	Feed costs	Breeding costs	Other costs
1	61	80	394	274	120	−106	34	−133	−31	−27	−1
1	61	100	1015	933	81	−8	59	6	−16	−27	6
1	61	120	1652	1666	−14	−101	64	34	−38	−27	8
1	243	80	146	−7	146	−1070	−110	−1050	−201	−24	−51
1	243	100	712	299	413	26	7	−348	9	−28	−13
1	243	120	1317	817	500	253	26	−238	53	−29	−7
2	61	80	429	258	171	−150	15	−235	−38	−25	−8
2	61	100	1035	811	224	54	36	−104	−3	−26	−1
2	61	120	1659	1452	208	98	48	−38	−1	−27	3
2	243	80	−42	−42	0	0	0	0	0	0	0
2	243	100	304	23	281	−524	−73	−744	−71	−25	−38
2	243	120	798	247	551	86	−25	−479	38	−26	−23

[1] Relative to average lactation curves.
[2] Value of new pregnancy ($) = sum of differences in milk sales + calf sales − replacement costs − feed costs − breeding costs − other costs. The sum of the differences may not add up to equal the value of the new pregnancy due to rounding.
[3] Replacement costs = heifer purchase costs − cow sales.
RPO = retention value ($).
Source: De Vries (2006).

Several interactions were observed. Early in lactation in first parity cows, the value of a new pregnancy decreased when relative milk yield increased. The low-producing cow (80% of average) had less opportunity to get pregnant before she was culled; therefore, her replacement cost was greater. At 120% milk yield, the −$14 value implied that delayed breeding was more profitable. Later in lactation, the value of a new pregnancy was greater for higher producing cows. In the second parity at day 61, the value of a new pregnancy at average milk yield was greater than at lower (80%) or higher (120%) milk yields. At day 243, the value of pregnancy was $0 for the low-producing cow because the optimal decision for that cow was to be culled, independent of pregnancy status. In the other cases, the value of a new pregnancy was greater for higher producing cows.

The average value of a new pregnancy in the study by De Vries (2006) for a typical U.S. herd was $278. This is a weighted average, depending on the proportion of cows in each stage of lactation, lactation number, and level of milk production. Eicker and Fetrow (2003) reported an average value of a new pregnancy of approximately $200 calculated with the dairy management information system DairyComp 305 (Valley Agriculture, Software, Tulare, CA). In programmed AI breeding protocols, Stevenson (2001) estimated the value of a new pregnancy at around $264, excluding the additional cost of the protocol compared to traditional breeding based on estrus.

Cost of Abortion

The cost of loss of pregnancy (abortion) after the first month of gestation was typically greater than the value of a new pregnancy, except in the rare case where the pregnant cow should be culled (De Vries, 2006). This was occasionally the case for low-producing cows in later lactations; the cost of the loss of pregnancy was then $0 because cull price was assumed to be independent of pregnancy. Costs ranged from $0 to $1373. The cost of the loss of pregnancy increased by stage of lactation at conception and by stage of gestation. Costs were typically greater for the high-producing cow except when the loss occurred early in lactation in the first parity. First-lactation cows had lower costs early in lactation, but greater costs later in lactation than older cows.

De Vries (2006) calculated an average cost of a loss of pregnancy at $555 per case, excluding any negative health effects associated with the loss of the pregnancy. The $555 is a weighted average, depending on the proportion of cows in each stage of lactation, stage of gestation, lactation number, and level of milk production. Others found that the loss caused by abortions was $624 (Pfeiffer et al., 1997), $640 (Thurmond & Picanso, 1990), $600–$800 (Eicker & Fetrow, 2003), $600–$1000 (Peter, 2000), and $1286 (Weersink et al., 2002). Most of these estimates were illustrations of special cases and not herd or group averages.

Realistic changes in inputs can have significant effects on herd statistics as shown in Table 12.8. As expected, increased daily milk yield, greater persistency, increased milk price, decreased heifer price, greater pregnancy rate, more opportunity to breed open cows, and decreased risk of premature culling were associated with increased profit per cow per year. Changes in annual cull rate, the value of a new pregnancy, and the cost of loss of pregnancy were not clearly associated with changes in profit per cow per year. Greater value of a new pregnancy was always associated with greater cost of the loss of pregnancy. Greater value of pregnancy was associated with

Table 12.8. Effect of changes in the inputs on selected herd statistics, including the value of a new pregnancy and the cost of a loss of pregnancy

	Herd statistic					
Input	Milk yield (kg/cow per year)	Days to conception	Annual cull rate (%)	Profit ($/cow per year)	Value of new pregnancy	Cost of loss of pregnancy
Daily milk yield[1]						
+20%	13,840	133	39	908	280	565
–20%	9019	141	33	–193	271	536
Persistency[2]						
+0.025 kg/day	11,602	163	33	414	227	488
–0.025 kg/day	11,442	129	38	337	314	603
Milk price						
$0.37/lb	11,552	133	40	1067	280	565
$0.25/lb	11,230	142	32	–348	269	531
Heifer price						
$1920	11,233	143	32	242	332	674
$1280	11,672	128	44	484	216	420
Pregnancy rate						
19.2%	11,437	131	33	393	235	529
12.8%	11,408	145	40	302	331	589
Last DIM to breed[3]						
365	11,445	134	37	351	282	560
274	11,479	125	39	334	310	594
Risk of prem. culling[4]						
+20%	11,423	137	38	323	268	540
–20%	11,431	137	34	387	289	573

[1] Relative to default lactation curves.
[2] Defined as linear decline in milk yield per day between day at peak yield and 305 days after calving.
[3] Last day in milk when breeding is allowed.
[4] Risk of premature culling relative to default risk of premature culling.
Source: De Vries (2006).

increased daily milk yield, reduced persistency of lactation, increased milk price, increased heifer price, decreased pregnancy rate, less opportunity to breed open cows, and decreased risk of premature culling. Major determinants of the value of pregnancy were persistency of lactation, heifer price, and pregnancy rate. The value of pregnancy was smaller when cows were given more opportunity to get pregnant before culling or when replacement costs were reduced.

Optimal Days to First Insemination

Because reproductive efficiency is not completely controlled, traditionally, the goal has been to breed cows as soon as possible after calving when the involution of the uterus and return to cyclicity were more or less completed (Weller & Folman, 1990; Stevenson & Phatak, 2005; LeBlanc, 2007). With the advent of rbST (recombinant bovine somatotropin) in 1994 and higher producing, more persistent cows through improvements in genetics and management, the optimal time of first breeding is being reconsidered. Furthermore, dairy producers in areas where rbST can no longer be used are also reconsidering their breeding programs because they believe that it has become more important to get cows pregnant earlier in lactation.

The calculations for optimal day of conception and the value of a new pregnancy are based on comparing cash flows from two identical cows that either conceive at different but predetermined stages of lactation, or one is newly pregnant and the other is not pregnant at a certain stage of lactation. In practice, dairy producers are faced with breeding decisions with the risk that the cow does not conceive. Figure 12.7 illustrates the economic loss from starting the first insemination earlier or later than the optimal day of first insemination (default assumptions described earlier). These results assume that the time of first breeding opportunity can be determined by the dairy producer, such as with a synchronized breeding protocol. In general, the optimal day of first insemination is earlier than the optimal day of conception, although the reverse can be true when fertility is very low. The difference is greater when the optimum days to conception are later in lactation. First parity cows again have flatter curves than older cows, similar to the economic loss curve for days to conception. The flatter the curve, the less important the optimal day to first insemination is compared to a nonoptimal day. The optimal day to first insemination was 77 days for the average first parity cow and 70 days for the average second and third parity cow. Low-producing cows should start their breeding period sooner, and first insemination for higher producing cows could be delayed, typically by 1 or 2 weeks.

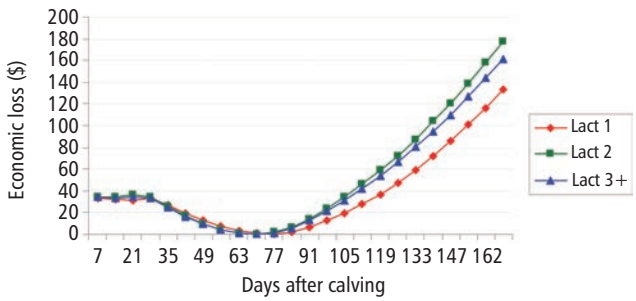

Figure 12.7. Economic loss ($/cow) caused by first insemination at various days after calving compared to the optimal day of first insemination. Optimal days to first insemination were 77, 70, and 70 for first, second, and third parity cow, respectively.

Variations in the assumptions have smaller effects on the optimal days to first breeding than on the optimal days to conception (De Vries, 2007). The trends in optimal days to first breeding follow those for optimal days to conception. Relative differences in milk production between cows in the same herd had greater effect on the optimal day to first breeding than the absolute level of milk production in the herd. These results are in agreement with the observation that the average voluntary waiting period in practice is approximately 56 days (DeJarnette et al., 2007; Miller et al., 2007), and furthermore, that first insemination for higher producing cows, especially in the first parity, is sometimes delayed by a few weeks (Weller & Folman, 1990; DeJarnette et al., 2007). In herds that depend on detection of estrus for the first breeding, the voluntary waiting period is necessarily shorter than the time of first insemination.

Insemination Value

The insemination value for individual cows is an estimate of the value of inseminating the cow at the breeding opportunity (ovulation) compared to not inseminating her at that opportunity. Typically, over the course of the lactation, the insemination value rises to a maximum and then declines again as shown in Table 12.9. The insemination value for first parity cows reaches a peak much later in lactation than older cows. This is a result of a more persistent lactation curve.

The insemination value is highly correlated with the value of a new pregnancy. However, the increase in value of pregnancy continues longer in the lactation than the insemination value. Early and late in lactation, the value of a new pregnancy may be positive whereas the insemination value is negative. The value of a new pregnancy is therefore less desirable for breeding decisions than the insemination value. The economic losses of using the

Table 12.9. Insemination value ($) for first and second parity cows by days after calving and level of milk yield[1]

	Insemination value, $					
	Lactation 1			Lactation 2		
Day after calving	–15%	Average	+15%	–15%	Average	+15%
Day 42	4	–8	–21	6	–1	–11
Day 155	106	109	99	97	124	130
Day 267	107	164	190	29	139	189
Day 365	19	127	188	–20	34	133

[1] Average milk production, +15% and –15% compared to the average daily yield.

value of a new pregnancy for insemination decisions are small, however.

The insemination values shown in Table 12.9 assumes that the next breeding opportunity is in 3 weeks, and that the risk that the breeding opportunity is followed by an insemination is 55% (which is equivalent to 38.2 days between inseminations). The optimal days to first insemination presented earlier assumed that the dairy producer controls the week of the first breeding opportunity. As a result, the insemination value early in lactation can be positive and suggests that the cow should be inseminated (because the next breeding opportunity is on average 3/55% = 5.45 weeks later), whereas the optimal time of first insemination could be just 1 or 2 weeks later. Thus, herds that do not control the first breeding opportunity should inseminate cows earlier than those that control the timing of the first breeding opportunity.

The level of milk production has a significant effect on the insemination value. The lower producing cow (–15%) had greater insemination values earlier in lactation, but these values were lower later in lactation. Low-producing cows have less time to get pregnant in their lactation before they should be culled. Therefore, it is important to get them pregnant early in lactation. Late in lactation, it becomes more important to get the higher producing cow pregnant (if she is still not pregnant). Higher producing cows should be allowed more time to become pregnant before they are culled. This is also observed in practice where average days to conception for higher producing cows are typically greater than for lower producing cows (Stevenson, 2004). More high-producing cows are allowed to conceive late in lactation and thus contribute to a longer average days to conception. In general, increased reproductive efficiency resulted in a lower insemination value early in lactation but a greater insemination value later in lactation. Further, increased persistency lowered the insemination value early in lactation. These results are in agreement with earlier findings (Dekkers et al., 1998).

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13

Managing Reproduction During Heat Stress in Dairy Cows

Peter J. Hansen

Abstract

Heat stress can compromise reproductive function of lactating dairy cows throughout much of the world. Among the key events associated with reduced reproductive function are reduced expression of estrus, disruptions in follicular and oocyte function, increased embryonic mortality, and reductions in fetal development. Reproductive function during heat stress can be improved by modifying animal housing to reduce the magnitude of heat stress. In addition, manipulation of physiological function can mitigate some deleterious effects of heat stress. Effects on estrus detection can be reduced by incorporation of estrus detection aids and eliminated by utilization of timed artificial insemination protocols. Effects on fertility can be reduced by use of embryo transfer. Other approaches, such as feeding antioxidants, offer some promise for improving fertility, whereas others, such as hormonal treatments, have not resulted in consistent improvements in fertility during heat stress. In the future, it may be possible to select cows for resistance to heat stress as genetic markers for thermotolerance at the physiological and cellular level are identified.

Impact of Heat Stress on Dairy Cow Fertility: A Widespread and Growing Problem

Heat stress adversely affects fertility of dairy cattle in most temperate regions of the world where dairy cattle are raised. The magnitude and duration of the reduction in fertility during seasonal heat stress is greater in warmer regions of the world (Al-Katanani et al., 1999; Huang et al., 2008). Nonetheless, fertility declines during summer in temperate regions (Oseni et al., 2003). Fertility has been reported to be lower in summer than in winter as far north as Edmonton, Canada (Ambrose et al., 2006). Moreover, there is evidence that the magnitude of effects of heat stress on fertility has been increasing over time (López-Gatius, 2003; Pszczola et al., 2009).

Given its importance in limiting reproductive function, management of heat stress should be an important priority on most dairy farms. This chapter will review what is known about effects of heat stress on physiological functions controlling reproduction and review the approaches used to minimize these effects.

Physiology of Heat Stress

Cows, like all mammals and birds, are homeotherms that, within the limits of circadian rythmicity, attempt to regulate their body temperature at a constant and high level (~38.3–38.6°C in cattle). Regulation is achieved by matching internal heat production for maintenance and other activities with heat loss to the environment. Heat is exchanged with the environment by conduction, convection, radiation, and evaporation. The magnitude of heat exchange through the first three modalities depends upon the gradient in temperature between the cow's surface and the surrounding environment. In cattle, evaporation occurs through sweating and panting as well as through forced wetting of the skin (e.g., when a cow comes in contact with sprinklers or misters). The

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amount of heat loss via evaporation depends upon the humidity of the surrounding air and the effective surface area of the animal engaged in evaporation (surface area of the skin for sweating and forced wetting and minute volume for respiratory heat loss).

Hyperthermia occurs when heat production exceeds the amount of heat lost to the environment. This state is more likely when heat loss to the environment is minimized. High air temperatures and intense solar radiation are two of the most important factors leading to hyperthermia, but high humidity and low wind speeds contribute to reduced heat loss (Buffington et al., 1981; Berman, 2005). Features of the animal also determine the magnitude of heat production and heat loss. Most important for dairy cattle is lactation. Milk synthesis is associated with a large increase in heat production. For example, heat production of cows producing an average of 31.6 kg milk/day was 48% higher than heat production of dry cows (Purwanto et al., 1990). The high heat production associated with lactation reduces capacity for thermoregulation during heat stress so lactating cows experience hyperthermia at lower air temperatures than nonlactating females. In a study in Wisconsin (Sartori et al., 2002), for example, lactating cows at an air temperature of 25°C had an average rectal temperature over 39.1°C whereas nonlactating heifers at the same temperature had an average rectal temperature near 38.4°C (Fig. 13.1). Furthermore, regulation of body temperature during hyperthermia can be reduced as milk yield increases (Berman et al., 1985; Berman, 2005). Not surprisingly, seasonal variation in fertility is much more pronounced for lactating females than for nonlactating heifers (Badinga et al., 1985; Chebel et al., 2007) and, as shown in Figure 13.2, seasonal variation in nonreturn rate is more pronounced in high-producing cows than in lower producing ones (Al-Katanani et al., 1999). Nonetheless, nonlactating heifers can experience heat stress and, in these cases, cooling can improve fertility (Moghaddam et al., 2009).

Despite the relationships between milk yield, heat production, and body temperature regulation, there was no relationship between milk yield and body temperature during heat stress for lactating dairy cows in a subtropical environment under confinement (Dikmen & Hansen, 2009) or grazing conditions (Dikmen et al., 2009). One possible explanation for this finding is, in hot climates, cows with superior ability for body temperature regulation are more likely to have high milk yield as a result.

Physiological adaptations during heat stress reduce the magnitude of heat production (e.g., decreased feed intake and milk yield) or increase heat loss (e.g., a decrease in peripheral vascular resistance, sweating, and panting) (see Kadzere et al., 2002 for review). Adaptations occur over a broad time span so that heifers exposed to heat stress for several weeks gained ability to minimize

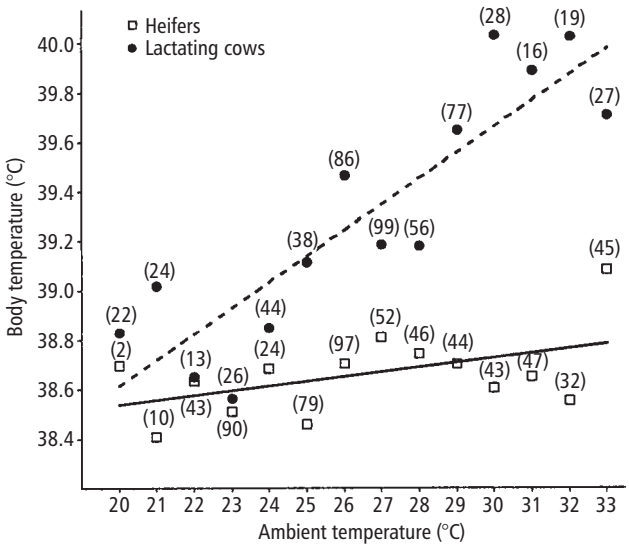

Figure 13.1. Effect of lactation on the relationship between air and body temperatures. Data are from lactating cows and nulliparous heifers in Wisconsin. Values within parentheses near each symbol represent the number of observations. From Sartori et al. (2002). Reproduced with permission of the *Journal of Dairy Science*.

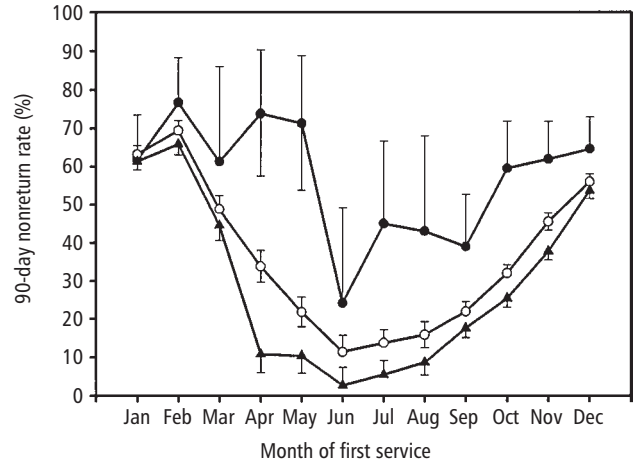

Figure 13.2. The effect of milk yield on seasonal variation in 90-day nonreturn rate in dairy cows in Florida and South Georgia. The term 90-day nonreturn rate signifies the percentage of cows that were not seen in estrus in the 90 days after insemination. The lines represent data for cows producing less than 10,000 lb of milk per lactation (closed circles), 10,000–20,000 lb (open circles), and greater than 20,000 lb (closed triangles). Data are from Al-Katanani et al. (1999), and the figure is reproduced with permission of the *Journal of Dairy Science.*

deleterious effects of stress (Weldy et al., 1964). As a result, effects of acute heat stress may be more severe for animals living in a cool environment than for cows living in a warm environment.

Adaptations extend to the genetic level. There is genetic variation in heat tolerance (Aguilar et al., 2009), including for days open (Oseni et al., 2004), and gene markers related to the magnitude of effects of heat stress on milk yield have been identified (Hayes et al., 2009). Thus, selection for thermotolerance should be possible. There may also be heterosis for body temperature regulation during heat stress because body temperatures in grazing cows exposed to heat stress were lower for Jersey × Holstein than for either parental breed (Dikmen et al., 2009). At the cellular level, *Bos indicus* embryos are more resistant to elevated temperature than *Bos taurus* embryos (see Hansen, 2004, 2007a for review).

Disruptions in Reproductive Function Caused by Heat Stress

Detection of Estrus

By several measurements, behavioral estrus is reduced by heat stress. Experimental heat stress reduced the length of estrus (Gangwar et al., 1965; Abilay et al., 1975), and estrous cows during the summer had reduced walking (López-Gatius et al., 2005) and mounting activities (Nebel et al., 1997). Reduced estrous activity probably involves a reduction in the preovulatory rise in circulating concentrations of estradiol-17β (Gwazdauskas et al., 1981; Gilad et al., 1993) as well as the physical lethargy produced by heat stress.

Given the effects of heat stress on behavioral estrus, detection of estrus becomes difficult. On a commercial dairy in Florida, for example, the percentage of undetected estrous periods were 76%–82% during June–September versus 44%–65% during October–May (Thatcher & Collier, 1986).

Oocyte and Follicular Development

Oocyte competence for fertilization and for the resultant embryo to develop to the blastocyst stage is compromised during heat stress (Rocha et al., 1998; Zeron et al., 2001; Al-Katanani et al., 2002a). Compromised oocyte development is, at least in part, the result of deviations in the pattern of follicular development. Follicular dominance is reduced by heat stress so that growth of the dominant follicle is reduced and the number of smaller-sized follicles increases (Badinga et al., 1993; Wolfenson et al., 1995). In addition, heat stress can reduce follicular androstenedione and estradiol-17β output (Roth et al., 2001a) as well as follicular (Wolfenson et al., 1997) and circulating concentrations of estradiol-17β (Wilson et al., 1998a,b). Effects of heat stress on follicular function involve reductions in secretion of luteinizing hormone (Wise et al., 1988a; Gilad et al., 1993) as well as direct effects of elevated temperature on follicular steroid synthesis (Wolfenson et al., 1997; Bridges et al., 2005).

The process of follicular and oocyte development in cattle is a lengthy one. It has been estimated to take 16 weeks for a primordial follicle to reach dominance (Webb & Campbell, 2007). Therefore, there is the potential for heat stress to compromise oocyte development at points many days or weeks before ovulation. Such a concept has been shown experimentally in sheep: Heat stress on day 12 of the estrous cycle before breeding reduced subsequent fertilization rate and lambing rate (Dutt, 1964). It is likely that some of the delay in restoration of fertility in the autumn after the end of heat stress in cattle (Al-Katanani et al., 1999; Huang et al., 2008) represents effects of heat stress on oocyte development. The exact period before ovulation that is sensitive to heat stress in cattle has not been defined exactly. However, Roth et al. (2001a) found a carry-over effect of heat stress on follicular function. In particular, follicular steroid production was compromised by experimentally applied heat stress occurring 20–26 days previously, that is, when follicles were 0.5–1 mm in diameter. Thus, there is the possibility that heat stress occurring at least 3 weeks before ovulation can affect subsequent fertility.

Oocyte Maturation

An elegant experiment was performed by Putney et al. (1989a) to demonstrate that heat stress can disrupt oocyte function during the process of oocyte maturation. Superovulated heifers were heat stressed in an environmental chamber for 10 h beginning at the onset of estrus. Animals were then cooled and insemination was performed at 15–20 h after estrus onset. Thus, heifers were not exposed to heat stress at insemination. Heifers subjected to this treatment did not experience a reduction in fertilization rate as compared to controls but did have a reduction in the proportion of embryos recovered at day 7 after estrus that were classified as normal. *In vitro*, also, exposure to elevated temperature during maturation can reduce the proportion of oocytes that complete nuclear maturation and increase the proportion with abnormal spindle formation and apoptotic pronuclei (Payton et al., 2004; Roth & Hansen, 2004, 2005; Ju et al., 2005). Additional effects of heat stress during the preovulatory period are a reduction in magnitude of the preovulatory surge in luteinizing hormone and estradiol (Gwazdauskas et al., 1981; Gilad et al., 1993).

Fertilization Process

While fertilization rate is reduced in the summer in lactating cows (Sartori et al., 2002), much of this fertilization failure probably represents defects in oocyte maturation described in the previous paragraph. There is little information as to whether the fertilization process itself is compromised by heat stress. Ejaculated sperm exposed to heat stress do not have reduced fertilizing capacity *in vitro* (Monterroso et al., 1995; Hendricks et al., 2009) and embryos formed from heat-shocked sperm have normal competence to develop to the blastocyst stage (Hendricks et al., 2009).

Inhibition of Early Embryonic Development

The preimplantation embryo rapidly transforms itself from an organism that is very susceptible to heat stress to one that is more resistant. Heat stress of superovulated cows at day 1 after estrus caused a reduction in the proportion of embryos that were blastocysts at day 8 after estrus whereas heat stress at days 3, 5, or 7 had no effect on development at day 8 (Ealy et al., 1993). In a retrospective study from California (Chebel et al., 2004), there was no association between occurrence of heat stress after insemination and conception rate although heat stress before insemination was related to conception rate. *In vitro*, too, embryos at the 2–4 cell stage of development are more likely to be blocked in development following exposure to elevated temperature than embryos at later stages (Edwards & Hansen, 1997; Sakatani et al., 2004). The biochemical mechanisms conferring thermotolerance are not well understood but could include a change in balance between free radical production and antioxidant systems that make embryos more resistant to free radical production induced by heat shock (Hansen, 2007b).

Pregnancy Loss and Fetal Development

There are discrepancies in the literature as to whether heat stress causes late embryonic or fetal losses in lactating cows. In California, Chebel et al. (2004) found no relationship between occurrence of heat stress before or after insemination on pregnancy loss between days 31 and 45 of pregnancy and Jousan et al. (2005), working in Florida, observed no seasonal variation in pregnancy loss between days 40–50 and 70–80 or between 70–80 and term. In contrast, García-Ispierto et al. (2006) found an association between warm weather and increased pregnancy loss between days 35–45 and day 90 of gestation for cows in Spain. One consistent effect of heat stress in late gestation is a reduction in fetal growth and in milk yield in the subsequent lactation (Collier et al., 1982; Wolfenson et al., 1988; do Amaral et al., 2009).

Heat Stress Risk Assessment

It is not clear how high body temperature must rise or for how long the cow must be hyperthermic before reproductive function is compromised. Probably the best estimate of the effect of hyperthermia comes from the study of Gwazdauskas et al. (1973). In that study, a 0.5°C increase in uterine temperature on the day of insemination above 38.6°C caused a decline in conception rate of 12.8%. Since uterine temperature was 0.2°C higher than rectal temperature, it can be estimated that fertility begins to be compromised at rectal temperatures of ~38.9°C (0.5°C above rectal temperature of 38.4°C).

The best way to assess whether cows are exposed to heat stress sufficient to cause hyperthermia is to measure rectal temperature directly. This can be easily performed by placing a mercury thermometer in the rectum for 1 min. Cows that are exposed to heat stress also have other symptoms such as increased respiration rate (≥60 breaths per minute), open mouth breathing, drooling, and dropping of the head.

Much effort has been made to identify environmental measurements that can predict heat stress. For lactating dairy cows, the upper critical temperature, defined as the air temperature above which hyperthermia occurs, has been estimated between 25 and 28°C (Berman et al., 1985; Dikmen & Hansen, 2009). Various indices have also been developed that combine various measurements of environmental conditions to estimate the magnitude of heat stress. The most common of these is the temperature humidity index (THI). At least in humid environments, the THI is not much more predictive of rectal temperature than dry bulb temperature (Dikmen & Hansen, 2009). The THI above which milk yield declines was estimated at 72–74 (Bohmanova et al., 2007) while the THI above which rectal temperature increases was estimated at 78 (Dikmen & Hansen, 2009).

Cooling Strategies to Minimize the Magnitude of Heat Stress

The most common approach to reduce effects of heat stress on dairy cattle is to change the environment to reduce the magnitude of heat stress that cows experience. Environmental modifications include provision of shade, placement of fans to increase wind speed, addition of sprinklers, misters, or foggers to promote evaporative heat loss at the surface of the cow (sprinklers) or in the surrounding air (misters or foggers), and providing access to cooling ponds (Tomaszewski et al., 2005; Collier et al., 2006; Nienaber & Hahn, 2007). Shade and sprinklers can even be successfully incorporated into pasture-based management systems (Kendall et al., 2007).

The decision as to the environmental modifications to be employed is a complicated one and depends to some

extent on the value of milk produced relative to the costs of construction and operation of the housing system. Thus, elaborate systems for cooling cows, such as the tunnel ventilation and cross-ventilation barns in which humidified air is pulled through a barn by fans mounted at one end (tunnel ventilation) or the side of the barn (cross ventilation) (Smith et al., 2006a,b), may not be cost-effective in all situations. The climate also has an influence on the choice of housing system. High prevailing humidities may limit the effectiveness of fogger and mister systems to evaporate water into the air while high prevailing air temperatures could limit effectiveness of fans for convective cooling. Water availability and opportunities for wastewater discharge could affect the type of evaporative cooling employed.

Unfortunately, there is little scientific information about the relative effectiveness of different cooling systems for dairy cows. In one study in Saudi Arabia, cows that were cooled by a combination of fans and sprayers had lower fertility than cows receiving high pressure misters in conjunction with curtains that limited external air currents (the Korral Kool® system, Mesa, AZ) (Ryan et al., 1992) (Table 13.1). This difference in fertility occurred even though average rectal temperature was not lower in the group subjected to misting.

As described earlier, there is a window in the reproductive process during which heat stress has greatest effects on events leading to pregnancy establishment. The period of thermosensitivity extends from the final stages of oocyte development (~21–30 days before ovulation; the bounds of oocyte thermosensitivity are not well characterized) through days 1–3 after insemination. Given this fact, it is possible to cool cows for a few critical days around ovulation to cause some improvement in fertility (Table 13.2).

It is difficult to totally prevent effects of heat stress on fertility through changes in animal housing alone. In Florida, for example, seasonal variation in pregnancy rate persisted in a herd where cows were cooled with sprinklers and fans (Hansen & Aréchiga, 1999). In Israel, Flamenbaum and Ezra (2006) observed that milk yield in the summer for intensively cooled herds was 96%–103% of that in winter. However, conception rate was 19% in summer versus 39% in winter for high-producing herds and 25% in summer versus 40% in winter for low-producing herds. The limited effectiveness of cooling systems means that other approaches to improve reproductive function must be implemented to maximize reproduction during heat stress.

Management of Cows to Reduce Effects of Heat Stress on Estrus Detection

Estrus Detection Devices

Estrus detection aids can enhance detection of estrus in cows whose behavioral symptoms of estrus are reduced

Table 13.1. Effect of two different evaporative cooling methods on pregnancy rate at first service for lactating cows in Saudi Arabia[1]

	Fans and sprayers		Korral Kool® high pressure misting system	
Temperature humidity index	Number	Percent pregnant	Number	Percent pregnant
<78.5	22	22.7	18	27.8
78.5–80.7	23	17.4	27	29.6
>80.7	29	20.7	30	33.3

[1] From Ryan et al. (1992).
Note: Days from calving to conception were lower ($P < 0.05$) for the Korral Kool group (118 vs. 147 days).

Table 13.2. Improvement of fertility in lactating dairy cows by provision of cooling for a limited number of days around the time of final oocyte development, ovulation, fertilization, and embryonic development

			No. pregnant /no. bred (%)			
Location	Cooling method	Cooling period[a]	Control	Cooled	P^b	Reference
Arizona	Air conditioning	0 to +4–6.5	13/61 (22%)	19/63 (30%)	N.S.	Stott & Wiersma, (1976)
Guadeloupe	Spraying	12 days, until day 10 post AI	2/15 (13%)	8/15 (53%)	0.05	Gauthier, 1983
Israel	Fans and sprinklers	–1 to +8 relative to estrus	8/22 (36%)	9/29 (31%)	N.S.	Her et al., 1988
Arizona	Various	8–16 days after prostaglandin	3/18 (16.7%)	10/35 (28.6%)	0.05	Wise et al., 1988b
Florida	Fans and sprinklers	8 days after prostaglandin	2/32 (6.2%)	8/50 (16.0%)	0.02[c]	Ealy et al., 1994

[a] Unless otherwise mentioned, days relative to estrus.
[b] N.S. = nonsignificant.
[c] $P = 0.02$ by ANOVA but nonsignificant by CATMOD.

by heat stress. In one study, conducted in Florida during the summer, applying tail chalk as an estrus detection aid increased the proportion of cows detected in estrus within 96 h following injection of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) from 24% to 43% (Ealy et al., 1994). Using dairy cows in North Carolina in the summer, Peralta et al. (2005) found that efficiency of detection of estrus was improved when visual observation of estrus was accompanied by use of a remote sensing device (HeatWatch™, CowChips LLC, Manalapan, OR, or ALPRO™, DeLaval, Kansas City, MO).

Bulls

Natural mating represents another approach for avoiding effects of heat stress on estrus detection. In fact, the percentage of breedings performed using artificial insemination (AI) across the United States declines slightly in the summer (Powell & Norman, 1990), either because dairy farmers are unwilling to go through the effort of inseminating cows artificially when pregnancy outcomes are low or because of the belief that fertility can be improved through use of bulls. Natural mating systems are more expensive in a majority of cases than AI programs although not in all (Overton, 2005). Also, male fertility can be affected for up to 60 days after heat stress (Hansen, 2009), and AI represents a technology for avoiding effect of heat stress on semen quality.

The major advantage expected to be accrued through the use of bulls is to bypass missed breeding opportunities caused by poor expression of estrus. De Vries et al. (2005) compared pregnancy rates (the proportion of cows eligible to be bred in a 21-day period that became pregnant, that is, the product of estrus detection rate × the proportion of inseminated cows that became pregnant) for herds in Florida and Georgia that utilized bulls predominantly (natural service herds; ≥90% of natural breedings), in part (mixed herds; 11%–89% of breedings naturally), or seldom (AI herds; ≤10% of breedings naturally). In the winter, pregnancy rates were similar for all three types of herds (pregnancy rates = 17.9%, 17.8%, and 18.0% for AI, mixed, and natural service herds, respectively). In the summer, there was a slight increase in pregnancy rate for herds using bulls (pregnancy rates = 8.1%, 9.1%, and 9.3% for AI, mixed, and natural service herds).

Timed Artificial Insemination (TAI)

Protocols for TAI are used to program the timing of ovulation so that insemination can be implemented at a fixed time and without the need for estrus detection. The use of these protocols in the summer can increase the rate at which cows get pregnant after the voluntary waiting period. This benefit accrues because cows are inseminated more frequently (i.e., all cows eligible for breeding are inseminated rather than only those detected in estrus) but not because cows are more fertile. As a result, the overall pregnancy rate (the proportion of cows eligible for breeding that are pregnant) and pregnancy rates at specific times postpartum (e.g., the proportion of cows pregnant at 90 days after calving) can be improved, but pregnancy rate per insemination is generally not improved. Typical results are shown in Table 13.3.

Management of Cows to Reduce Effects of Heat Stress on Fertility

Hormonal Treatments

Much effort, largely unsuccessful, has gone into identifying hormonal treatments to enhance fertility in heat-stressed cows. One often-observed characteristic of cows exposed chronically to heat stress is a reduction in circulating concentrations of progesterone (Wolfenson et al., 2000). However, injection of human chorionic gonadotropin at day 5 of the estrous cycle to increase circulating progesterone concentrations did not improve the proportion of heat-stressed cows that became pregnant after insemination (Schmitt et al., 1996; Santos et al., 2001). Bovine somatotropin treatment might be expected to increase fertility of heat-stressed cows because it induces secretion of insulin-like growth factor-1 which, in turn, can improve embryo survival during summer (Block & Hansen, 2007). In fact, however, there was no significant effect of administration of bovine somatotropin on fertility of lactating cows exposed to heat stress (Jousan et al., 2007; Bell et al., 2008).

There are some indications that administration of gonadotropin-releasing hormone (GnRH) can improve fertility during heat stress but more experiments are needed to confirm these indications. López-Gatius et al. (2006) found that pregnancy rate per insemination was improved from 20.6% in control cows to 30.8% for cows treated with GnRH at insemination and 35.4% for cows receiving GnRH at insemination and 12 days later. In another series of experiments, injection of GnRH at days 14–15 after estrus to delay luteolysis was generally without effect on fertility (Franco et al., 2006).

Antioxidants

Increased production of reactive oxygen species (ROS) has been implicated in the deleterious effects of elevated temperature on embryonic development. In particular, exposure of embryos to 41°C *in vitro* increased ROS production at days 0 and 2 relative to insemination but

Table 13.3. Effectiveness of timed insemination protocols for increasing pregnancy rates of lactating Holsteins when implemented during periods of heat stress in Florida (experiments 1–3) and Kansas (experiment 4)[1]

				Pregnancy rate		
Exp.[2]	Treatment[3]	*n*	Interval, calving to first service (days)	At first service	At day 90 postpartum	At day 120 postpartum
1	Estrus	184	82.4 ± 1.0	12.5 ± 2.5	9.8 ± 2.5	30.4 ± 3.5
	TAI	169	72.4 ± 1.0***	13.6 ± 2.6	16.6 ± 2.6*	32.7 ± 3.6
2	Estrus	35	58.1 ± 1.7	8.6 ± 5.1	14.3 ± 7.2	37.1 ± 8.3
	TAI	35	51.7 ± 1.7*	11.4 ± 5.1	34.3 ± 7.1†	62.9 ± 8.3*
3	PGF	156	91.0 ± 1.9	4.8 ± 2.5		16.5 ± 3.5
	TAI	148	58.7 ± 2.1*	13.9 ± 2.6*		27.0 ± 3.6*
4	SS	128	[4]	32.0	17.9[5]	
	TAI	207		33.3	33.3**	

[1] Data represent least-squares means ± SEM.
[2] Experiments 1 and 2: Aréchiga et al. (1998a); experiment 3: de la Sota et al. (1998); experiment 4: Cartmill et al. (2001).
[3] Estrus = breeding at each observed estrus beginning at day 70 (experiment 1) or day 50 (experiment 2) postpartum; TAI = timed artificial insemination programmed for day 70 (experiment 1), 50 (experiment 2), 60 (experiment 3), or 50–70 after calving (experiment 4) followed by breeding at all observed estrous periods thereafter; PGF = injection of $PGF_{2\alpha}$ at day 57 days postpartum and breeding at all detected estrous periods thereafter; SS = Select Synch; GnRH followed by PGF 7 days later and breeding at detected estrus for the next 21 days.
[4] A total of 58.7% of Select Synch cows were inseminated within 7 days after PGF versus 100% of TAI cows.
[5] Measured at 27–30 days after anticipated day of insemination (77–100 days postpartum).
* $P < 0.05$;
** $P < 0.01$;
*** $P < 0.001$.
† $P < 0.10$ ($P = 0.055$).

not at days 4 or 6 (Sakatani et al., 2004). The stages of embryonic development at which ROS increased are those where thermosensitivity is maximal (Ealy et al., 1993; Edwards & Hansen, 1997; Sakatani et al., 2004). In addition, intracellular concentrations of the cytosolic antioxidant glutathione are lowest in bovine embryos during early cleavage states (Lim et al., 1996). Thus, redox status may play a critical role in developmental changes in embryonic resistance to heat stress.

Despite these observations, fertility of lactating cows exposed to heat stress has generally not been improved by provision of antioxidants. Among the ineffective treatments has been administration of vitamin E at insemination (Ealy et al., 1994), injections of β-carotene at –6, –3, and 0 day relative to insemination (Aréchiga et al., 1998b), and multiple injections of vitamin E and selenium before and after calving (Paula-Lopes et al., 2003). There is one report indicating that feeding supplemental β-carotene for at least 90 days beginning at ~15 days after calving increased the proportion of cows that were pregnant at 120 days postpartum (35% vs. 21%) (Aréchiga et al., 1998a). In this same study, there was a nonsignificant tendency for the proportion of cows pregnant to first service to be higher for cows receiving supplemental β-carotene (14.6% vs. 9.3%). Additional experimentation involving long-term feeding of antioxidants to improve fertility during heat stress is warranted.

Follicular Turnover at the End of the Hot Season

Work in Israel has focused on hastening the restoration of fertility in the autumn by turning over follicles that were damaged by heat stress in the preceding summer. Oocyte competence in the autumn, as measured by potential to cleave and form embryos *in vitro*, could be improved by repeated follicular aspiration (Roth et al., 2001b) or stimulation of follicular growth with follicle-stimulating hormone or bovine somatotropin (Roth et al., 2002). Thus, these treatments, or repeated use of ovulation synchronization protocols that stimulate follicular turnover such as the Ovsynch procedure, may be

effective for improving fertility in the month or two after the end of heat stress.

Embryo Transfer

The most effective way to improve fertility in the summer is through the use of embryo transfer as shown in Figure 13.3. Embryos are typically transferred as morula or blastocysts at day 7 after estrus and, by this time, the embryo has become substantially resistant to disruption by maternal hyperthermia (Ealy et al., 1993). Moreover, effects of heat stress on oocyte competence, fertilization, and early development are bypassed. Several experiments have validated the effectiveness of embryo transfer for improving pregnancy rate in lactating cows subjected to heat stress. Positive results have been obtained when using embryos produced by superovulation (Putney et al., 1989b; Drost et al., 1999; Rodriques et al., 2004) or embryos *in vitro* fertilization (Ambrose et al., 1999; Al-Katanani et al., 2002b). Indeed, in a large-scale study in Brazil, seasonal variation in fertility was eliminated by the use of embryo transfer (Rodriques et al., 2004) (Fig. 13.3).

There are limitations to the use of embryo transfer as an assisted reproduction technique in heat-stressed cows. The cost of production of embryos can be prohibitive; the most inexpensive embryo is likely to be the embryo produced *in vitro* with oocytes collected from ovaries harvested from an abattoir. Unfortunately, pregnancy rates are lower for embryos produced *in vitro* than for embryos produced *in vivo* (Hansen & Block, 2004) and, as shown in Figure 13.3, embryos produced *in vitro* have a poor probability of surviving cryopreservation (Al-Katanani et al., 2002b). Many of these obstacles can be overcome with refinements in the techniques for embryo production, and embryo transfer remains the only technology that has a major effect on improving fertility during heat stress.

Genetic Selection

A largely unexplored approach to reducing effects of heat stress in dairy cattle is genetic selection for resistance to heat stress. Progress in selecting dairy cattle with superior ability to regulate body temperature should be possible (Aguilar et al., 2009), and identification of gene markers for thermotolerance (Hayes et al., 2009) creates new opportunities based on molecular genetics for doing so. It may also be possible to increase thermal tolerance by crossbreeding. Jersey × Holstein cows experienced lower temperatures on pasture during heat stress than Holstein or Jersey cows (Dikmen et al., 2009). Interestingly, the pregnancy rate per insemination was greater for lactating Holsteins under heat stress when Gyr semen was used than when Holstein semen was used (Pegorer et al., 2007). Such an effect could represent heterosis expressed by the developing embryo or the fact that *B. indicus* embryos have superior thermotolerance (see Hansen, 2004 for review).

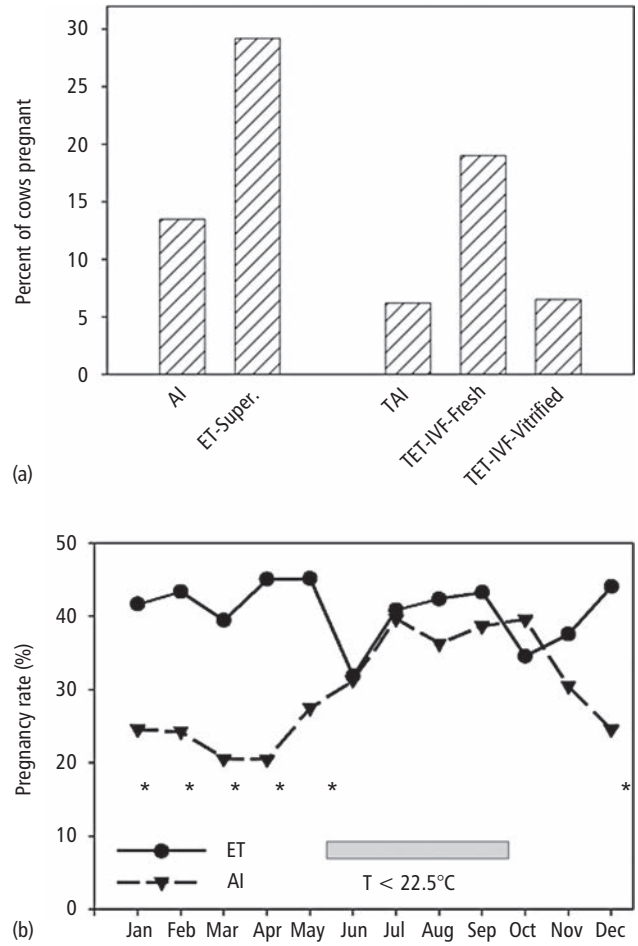

Figure 13.3. Improvement of fertility in lactating dairy cows exposed to heat stress through the use of embryo transfer. Shown in panel A are the results of two studies conducted during the summer in Florida to compare pregnancy rates for cows bred by artificial insemination (pregnant/cow inseminated) and cows received an embryo (pregnant/embryo transferred). The study represented in the first two bars involved comparison of insemination (AI) with transfer of a fresh embryo produced by superovulation (ET-Super.) (Putney et al., 1989b). The other bars show results from a study in which cows were subjected to the Ovsynch protocol and then either inseminated (TAI) or used to transfer a fresh (TET-IVF-Fresh) or vitrified embryo (TET-IVF-Vitrified) produced by *in vitro* fertilization (Al-Katanani et al., 2002b). Shown in Panel B are results from an experiment in Brazil where lactating Holstein cows were either inseminated or received a fresh or frozen-thawed embryo produced by superovulation (Rodriques et al., 2004). Months in which the average ambient air temperature was less than 22.5°C are shown with the gray bar. The figure is reproduced from Hansen (2007a) with permission of *Theriogenology.*

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14

Immunology and Vaccination of Dairy Cattle

Victor Cortese

Abstract

An in-depth understanding of the immune system is important for managing all aspects of the dairy. Improper handling of the immune system precalving can lead to increased postcalving problems and decreased milk production and increased reproductive failures. Improper knowledge of the immune system can lead to increased calf problems that will lead to life-long decreases in milk production and increased health problems and culling rates. This chapter will cover current information on the immune system of the dairy animal and discuss possible interventions that can improve immunologic function and health.

Introduction

In order to scientifically choose a vaccine or design a particular vaccination program for today's dairies, it is necessary to consider many variables (Senogles et al., 1978). The increased movement and purchasing of cattle seen with today's larger herds puts additional stress on the vaccine program as disease risk rises. Thus, vaccine programs need to be based on more science than ever before. When designing a vaccination program, a good history is needed before the program can be built. This should include

1. Presence and degree of challenge of the particular diseases on the dairy.
2. Management practices on the facility that lend themselves to or hinder the implementation of vaccination programs.
3. At what times or ages are the disease problems occurring and are they associated with any stresses?
4. What is the status of the herd? Is it open or closed? Are the owners purchasing animals and at what age? Are the calves home raised or grown by others? What age are they returning?
5. What is the breeding program? Are cleanup bulls used? Source of the bulls and age of the bulls at purchase.

There are also some basic questions to ask about specific vaccines that are being considered for inclusion in the vaccination program:

1. What immune system components are necessary to afford protection against various diseases?
2. Some basic immunology concepts.
3. The information that is available on products being considered and the source and quality of the information.
4. Label indications for duration of immunity and maternal antibody interference.
5. Warnings or restrictions on the use of a particular vaccine.

Challenge

The level of disease challenge and degree of protection are in a continual state of fluctuation on a dairy and in a particular animal. The level of protection is different in every vaccinated animal due to biological variability and day-to-day stresses the animal may be undergoing.

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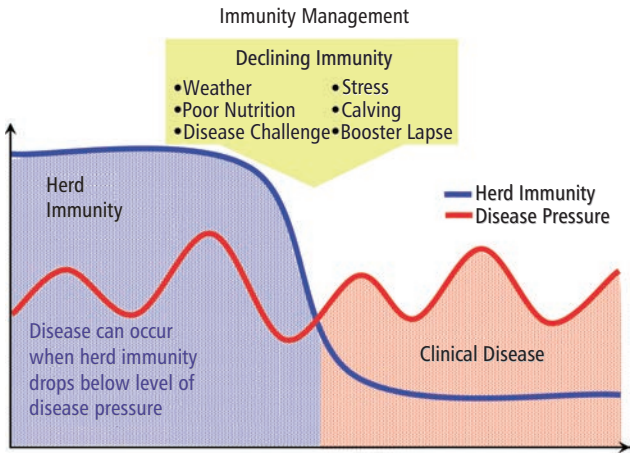

Figure 14.1. Various stresses or overwhelming exposure to infectious agents can lead to clinical disease.

The same is true with the amount of exposure to a pathogen. Overwhelming challenge can override the immunity and lead to disease even in well-vaccinated animals as shown in Figure 14.1.

Timing of Disease

Many farms will have consistent times when certain diseases occur. The timing may give some insight into stresses that are occurring in management of the cattle. Correcting these stresses can have a positive impact on vaccination and lessen disease susceptibility. Furthermore, this type of history is helpful to determine the timing of vaccinations. This is a concept that is often underutilized in veterinary medicine. Knowing when a problem has historically occurred will allow vaccinations to be scheduled as to when they will give maximum immune responses in preparation for anticipated challenges. As a general rule, vaccines should precede the anticipated problem by at least 2 weeks.

Immunology of Dairy Cattle

Development of the Prenatal Immune System

The immune system of all species of mammals begins development fairly early in gestation. As the fetus grows, the immune system goes through many changes as cells appear and become specialized. In general, the shorter the gestation period, the less developed the immune system is at birth (Senogles et al., 1978). However, the fetus does become immunocompetent to many diseases while *in utero*. In calves, this has been demonstrated with a wide variety of diseases (Senogles et al., 1978; Hawser et al., 1986; Tizard, 1992; Hein, 1994). For these types of diseases precolostral titers from the neonate can be used for diagnostic determination of fetal exposures. The primordial thymus can be seen in both fetal lambs and calves between days 27 and 30 as an epithelial chord (as a percentage of body weight, the thymus reaches its maximum size near mid-gestation then rapidly decreases after birth). Actual regression of the thymus begins around puberty and the extent and speed in which it regresses will vary by husbandry practices and genetics. By the time of first heat cycle, the thymus' function as an immune gland is almost completely gone.

The cells that initially infiltrate the thymus are of unknown origin, but thymic development and differentiation of thymocytes into specific cluster of differentiation (CD) cell lines occurs during gestation. Some of this development and differentiation can occur in secondary lymphoid organs as well. B cells, by contrast, develop and differentiate in the fetal bone marrow. There is a steady increase in the peripheral lymphocytes throughout gestation (Senogles et al., 1978). The majority of these circulating fetal lymphocytes are T cells. At the same time that lymphocytes are developing in the fetus, development and expansion of other white blood cell populations is occurring.

The Neonatal Immune System

The systemic immune system is fully developed, albeit immature, in the neonate at the time of birth. However, the local immune system goes through rapid development after birth. Susceptibility of the newborn to pathogens is not due to any inherent inability to mount an immune response, but is due to the fact that their immune system is unprimed, and the local immune system is underdeveloped. Although there are higher numbers of phagocytic cells in the neonate, the function of these cells is decreased (in calves, these deficiencies are found up to 4 months of age; Hawser et al., 1986). Complement is from 12% to 60% of adult levels at birth. Complement will not reach adult levels in calves until they are 6 months of age. There is a slow maturation of the immune system in mammals. As an animal approaches sexual maturity and begins to cycle, the immune system also matures. In cattle, most of the immune system maturity is seen by 5–8 months of age. For example, T cells (CD4+, CD8+, and TCR$\gamma\delta$+) do not reach peak levels until the animal is 8 months of age (Hein, 1994). This does not mean a young calf cannot respond to antigens, but the response will be weaker, slower, and easier to overcome. For all practical purposes, this immaturity may lead to moderation of disease rather than complete prevention. Since the placenta is of the epitheliochorial type in food animal species (cattle, pigs, sheep), there is no transplacental transfer of antibodies or white blood cells. Therefore, no discussion on

bovine neonatal immunology is complete without a discussion on an important component of the newborn calf's defense mechanism, colostrum.

Colostrum

Colostrum is the most important example of passive immunity. Defined as the "first" secretions from the mammary gland present after birth, colostrum has many known and unknown properties and components. The information on both the short- and long-term impacts of colostrum in calves continues to grow. Not only does good passive transfer impact morbidity and mortality in the young calf, (Rischen, 1981; Boland et al., 1995; Robison et al., 1998), but it also has a positive impact on long-term health and production (Wittum and Perino, 1995; Faber et al., 2005; Dewell et al., 2006). Constituents of colostrum include concentrated levels of antibodies and many of the immune cells (B cells, CD cells, macrophages, and neutrophils), which are fully functional after absorption by the calf (Riedel-Caspari & Schmidt, 1991). Additional components of the immune system such as interferon are transferred via colostrum (Jacobsen & Arbtan, 1992) along with many important nutrients (Schnorr & Pearson, 1984). The primary colostral antibody in most domestic species is immunoglobulin (Ig) class G; in ruminants this is further defined as IgG1. The function of the various cells found in colostrum is still undergoing much research. The cells are known to enhance defense mechanisms in the newborn animal in the following ways: transfer of cell-mediated immunity, enhanced passive transfer of Igs stimulate development of neonatal antigen-presenting cells, local bactericidal and phagocytic activity in the digestive tract, and increased lymphocyte activity (Saif et al., 1984; Duhamel, 1993; Reber & Hippen, 2005). Recent research has demonstrated that only cells that have been exposed to the colostral environment are absorbed and traffic into the neonatal bloodstream. These cells also demonstrate different homing patterns. Finally, calves deprived of maternal colostral leukocytes upregulate receptors associated with physiological stress (Osterstock et al., 2003).

These cells contained in colostrum are destroyed by freezing and naturally disappear from the calf between 3 and 5 weeks of age (Saif et al., 1984). The long-term impacts of these cells on health and/or production of calves is not well understood at this time.

Colostrum Absorption

When calves are born, the epithelial cells that line the digestive tract allow absorption of colostral proteins via pinocytosis. As soon as the digestive tract is stimulated by ingestion of any material, this population of cells begins to change to those that no longer permit absorption. By 6 h after birth, only about 50% of the absorptive capacity remains, by 8 h 33%, and by 24 h no absorption is typically seen (Jacobsen & Arbtan, 1992). So colostrum transfer is a function of quality and quantity of the colostrum as well as the timing of colostral administration. In the Holstein breed, the first feeding should be a minimum of 3 L (3 qt) and preferably 3.78 L (4 qt) of high-quality, clean colostrum. Also, colostrum high in red blood cells may exacerbate any diarrhea caused by gram-negative bacteria (Riedel-Caspari, 1993). In spite of all of the information regarding the importance of colostrum administration to the calf, some degree of failure of passive transfer is common even in beef calves (Schnorr & Pearson, 1984; United States Department of Agriculture, 2002b). Colostral supplements are available as well as products for oral or systemic administration, which contain specific antibodies or general IgG concentrations. There is tremendous variability in the IgG concentration of colostral supplements (Haines et al., 1990). Although mixed results have been observed pertaining to the efficacy of these products, in colostrums-deprived calves, they may have a significant value in decreasing mortality and/or severity of disease (Godden, 2008).

Vaccination to Improve Colostral Quality

It has long been thought that vaccines administered to a cow before calving will increase colostral antibodies against specific antigens. This has been best demonstrated with vaccines against neonatal diarrhea pathogens that are administered to cows. These vaccines are designed to increase the colostral antibody concentration against specific organisms that cause diarrhea in calves such as *Escherichia coli*, rotavirus, and coronavirus (Saif et al., 1983; Saif et al., 1984; Murakami et al., 1985). However, little research has been done looking at other vaccines and their impact on colostral antibodies. While one study demonstrated that vaccinating cows with a modified live viral vaccine increased colostral antibodies (Ellis et al., 1986), a recent study with inactivated viral vaccination of cows did not show the same response (Osterstock et al., 2003). One Israeli study actually demonstrated decreased colostral antibodies when cows were vaccinated before calving (Brenner et al., 1997). If a vaccine is being incorporated into a program primarily to improve colostral transfer of antibodies, then studies should be requested that demonstrate the vaccine's ability to produce the desired effect.

Maternal Antibody Interference Revisited

One of the commonly held beliefs in neonatal immunology is that the presence of maternal antibody will block

Table 14.1. Diseases with research that has assessed maternal antibody interference in cattle

Primarily cell mediated protection—vaccination not blocked by maternal antibody	Primary antibody protection—vaccination blocked by maternal antibody
BRSV	Bovine viral diarrhea
BHV-1	*Mannheimia haemolytica*
Parainfluenza virus	*Pasteurella multocida*
Leptospira borgpetersenii	
Pseudorabies	

the immune responses associated with vaccination. This has been based on vaccinating animals followed by evaluating subsequent levels of antibody titers. It is clear from many studies that if animals are vaccinated in the presence of high levels of maternal antibody to that antigen, they may not display increased antibody titers following vaccination (Brar et al., 1978; Menanteau-Horta et al., 1985). However, recent studies have shown both the formation of B cell memory responses (Parker et al., 1983; Kimman et al., 1989; Pitcher, 1996) as well as cell-mediated immune responses in the face of maternal antibody (Parker et al., 1983) when attenuated vaccines were used. Similar responses have been reported in laboratory animals as well (Jewett & Armstrong, 1990; Forsthuber et al., 1996; Ridge et al., 1996; Sarzotti et al., 1996). It is clear from these studies that maternal antibody interference of vaccines is not as absolute as once thought. The immune status of the animal, particularly against that antigen, the specific antigen, and presentation of that antigen should be considered when trying to design vaccination programs when maternal antibody may be present. In summary, work published to date has demonstrated that vaccination against diseases that have a primary cell-mediated protective mechanism may be more likely to stimulate an immune response in the face of maternal antibody than those of which humoral immunity is the primary protective mechanism as shown in Table 14.1.

Impact of Stress

Stress impacts the calf's immune system as it does in older animals. There are several factors that can affect the immune system that are unique to the neonatal animal. The calving process has a dramatic impact on the newborn's immune system due to corticosteroid release. Furthermore, the newborn has an increased number of suppressor T cells. These factors along with others dramatically decrease systemic immune responses for the first week of life. Recent research has demonstrated that there is actually a decrease in the immune response of neonatal calves. After birth, there is a decrease in immune responses until day 3 when they are at their lowest levels (Rajaraman et al., 1997). By day 5, these responses are back to level of immune responses seen on the day of birth. Systemically administered vaccinations during this time should be avoided due to these decreased responses. Vaccination immediately after birth may even have undesired effects (Bryan & Fenton, 1994). Furthermore, other stresses should be avoided in the young calf to try and maintain immune system integrity in the immunologically frail newborn. Procedures such as castration, dehorning, weaning, and movement need to be considered as stresses that have the potential to decrease immune system function temporarily. The impact of stress on the older cattle has been extensively studied (Wegner & Schuh, 1974; Blecha & Boyles, 1984; Binkhorst & Hendricks, 1986; VonTungeln, 1986; Cai & Weston, 1994). Decreased immune function can be measured beginning 4 weeks prior to calving and does not rebound to normal levels until 5 weeks postcalving. These decreased immune responses include delayed inflammation by reducing efficiency of immune surveillance by neutrophils, decreased phagocytic cell function, increased trafficking of $\delta\gamma$ T cells into epithelial sites, decreased IFN-γ secretion by lymphocytes, decreased antibody production by B cells, and decreased Th1 responses. This immune suppression may also delay or impair response to vaccines: Therefore, postparturient or poststress vaccination should be delayed until reasonable immune responses can be expected.

Choosing Vaccines

Assessing Vaccine Efficacy

Vaccine efficacy can be extremely difficult for the practitioner to assess. Traditionally, serologic data showing pre- and postvaccination titers has been equated to protection. For many diseases, there is a poor correlation between an antibody being measured and the protection generated by the vaccine in the animal (Kaeberle, 1991). Recently, cell-mediated immune function tests have been added to show a more complete stimulation of the immune response after vaccination (Abbas et al., 1991). Although this gives more information on the vaccine, it still does not answer the basic question on how well a vaccine really protects. This can only be answered by well-designed challenge studies. In order to assess a challenge study, the following information is needed:

1. Trial design including animal characteristics
2. Statistical analysis of the results

3. Route of administration of the challenge
4. Characteristics of the challenge organism
5. The method for clinical score assignment
6. Publication of the results in a peer-reviewed article
7. Impact on the challenge on the control group

Unfortunately, for many of our diseases, the challenge model is not well established.

Field trials are even harder to assess but are valuable at answering the effectiveness (i.e., the efficacy in a particular situation) and efficiency of vaccines (cost-effectiveness of a vaccine; Naggan, 1994). There are several good references on field trial analysis available (Meinert, 1986; Ribble, 1986). The best place to begin the analysis of a vaccine is with the label and accompanying insert. The United States Department of Agriculture grants one of five different levels of protection based on the data submitted for vaccine licensing (United States Department of Agriculture, 2002a; Cortese, 2009). The inserts will also list any duration of immunity studies and warning and precautions. Familiarity with the labels and a periodic review for all vaccines that are recommended in the program is essential for proper vaccination program design.

Modified Live Versus Inactivated Vaccines

Each company's development and manufacture of cattle vaccines is different; thus, the composition of the vaccine will vary dramatically among different manufacturers. Outlines of production are proprietary for each manufacturer; however, some information can be found in technical and marketing pieces. For example, some viral vaccines are grown on bovine-derived kidney cell lines whereas others are grown on porcine-derived kidney cells. Some vaccines are grown on only calf serum and some are grown on both calf and fetal calf serum. Differences in passages may be found as well. The variability is seen in the following areas:

1. Strain(s) chosen for the vaccine
2. Number of passages chosen in the growth
3. Growth medium
4. Number of viral or bacterial particles in the vaccine particles

There are basically three different technologies available today in cattle viral and bacterial vaccines (Duffus, 1989; Tizard, 1992).

1. Modified live (attenuated) vaccines contain living bacterial or viral organisms. They are usually collected from a field disease and then grown in abnormal host cells (viral) or media (bacterial) to change or attenuate the pathogen. Each time the pathogen is grown through a replication it is called a passage, and it is administered back to the animal to see if it is still virulent. After several passages, the pathogen will begin to lose virulence factors since it cannot cause "disease" in these unnatural host cells. Once the pathogen can no longer cause "disease" in the target species, it is then tested to see if it can confer protection. The final vaccine is usually passed a number of times beyond the passage where virulence is no longer seen. This decreases the risk of reversion to a virulent pathogen. These vaccines usually require good quality control to decrease the risk of a contaminant entering the vaccine.
2. Inactivated (killed) vaccines are easier to develop since virulence after growth is not a problem. The same pathogen is isolated from a disease outbreak. The pathogen is grown and then chemically or physically killed. The inactivation is usually achieved by either adding a chemical to the pathogens or using ultraviolet rays. The major concern with inactivation is the potential loss of important epitopes. An adjuvant is normally added to inactivated vaccines to heighten the immune response. The vaccine is then tested for efficacy.
3. Genetically engineered vaccines have been altered genetically usually through a mutation. This mutation may be induced by several different methods, but the ensuing bacterium or virus has different properties that may alter virulence or growth characteristics. Most of these vaccines are modified live mutants (temperature-sensitive viral vaccines; streptomycin-dependent *Pasteurellas*), but inactivated marker vaccines are also genetically engineered. These vaccines have been engineered to delete a gene and cause an immune response deficient in antibodies to a certain epitope, allowing diagnostics to differentiate between vaccine and natural exposure responses (gene-deleted infectious bovine rhinotracheitis vaccines [IBRVs]).

Designing a Vaccination Program

Vaccination programs in a cowherd need to be custom-designed for the particular needs of the herd. Vaccination programs in the replacement stock have two specific goals that need to be met. The first is to protect the calf against any pathogens that are prevalent in the calves. The second is to prepare the calf for entry into the adult herd with a good foundation of protection from which to build herd immunity. The use of many different types of vaccines is routinely done very early in veal, dairy beef, and dairy replacement heifers particularly where early disease prevention is needed. Effectiveness of these programs is an interaction of several factors, including

antigen (i.e., IBR vs. *Pasteurella hemolytica*) and vaccine type (i.e., modified live or inactivated), age of the calf, presence of maternal antibody, other stress factors present at the time of vaccination, and timing of disease–agent exposure. Vaccines that utilize the mucosal immune system have been tested and licensed for use in the young calf, including the newborn. These vaccines include modified live, intranasal IBR/parainfluenza type 3 (PI3) vaccines, modified live, oral rotavirus/coronavirus vaccine, and new intranasal vaccines containing either bovine viral diarrhea virus (BVDV) types 1 and 2, bovine herpesvirus (BHV)-1, PI3, and bovine respiratory syncytial virus (BRSV) or BRSV in combination with PI3 and adenovirus. For BRSV, in which limited replication occurs with systemic modified live vaccination, intranasal administration may be the most effective route (Ellis et al., 2007). Exact timing of early vaccination will vary somewhat depending on antigen and presentation. One study has shown that initial systemic vaccination for the four primary viral diseases (BVDV, IBRV, BRSV, and PI3) has little impact when administered during the 3-week to 5-week of age window in dairy calves (Abbas et al., 1991). This corresponds to the time frame in which maternal T cells are disappearing from the calf (Saif et al., 1983; Haines et al., 1990). Several other studies have looked at vaccinating calves before 3 weeks of age with good response (Parker et al., 1983; Cortese, 1998; Cortese et al., 1998). In general, vaccination in the young calf should precede anticipated or historical times of disease by at least 10 days, allowing the immune system to respond before exposure. If a booster dose is required, then the booster should be given at least 10 days before the expected disease occurrence. Although in its infancy, the use of vaccination programs in young food animals is gaining popularity, and more research is needed to further define protection and the timing required by different vaccines in the neonate.

As discussed above, vaccination programs are tailor-made to each dairy; however, there are some basic vaccination recommendations for today's dairy herds. The cornerstone of the herd program is based first on protection against high-prevalence diseases that can have catastrophic impacts on the dairy when infections occur. In North America and many parts of the world, the minimum vaccination program should be built around the four major viral diseases: BVDV (types 1 and 2), BHV-1, and BRSV. Many would also include vaccination against the five primary *Leptospira* serovars of cattle due to the potential for high abortion rates, as well as the major *Clostridia* diseases, core endotoxin vaccines, and *Brucella*.

This should be the cornerstone of the program; other pathogens are then optional and are added depending on herd problems or potential risk. At least one five way

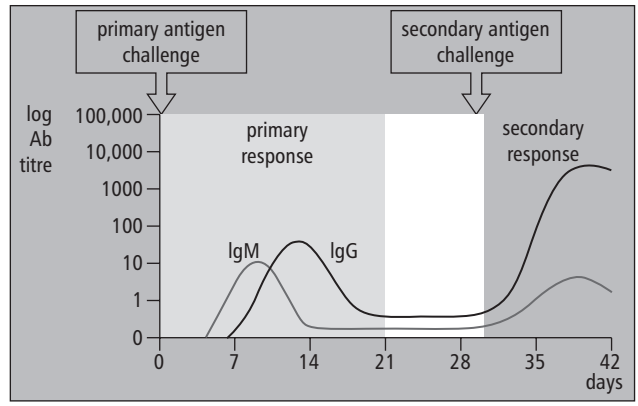

Figure 14.2. The importance of booster doses when required are shown in this graph. *Source*: Roitt, I., Brostoff, J., Male, D. (1998). *Immunology*, 4th ed. Philadelphia: Mosby Press.

modified live viral vaccine should be included in the vaccination program for replacement animals prior to first breeding to establish a strong baseline immunity against BVDV, BRSV, and BHV (Blecha, 1990; von Boehmer & Kisielow, 1991; Godson et al., 1992; Hoffman, 1992; Denis et al., 1994).

Booster Importance

It is important to follow the label directions for administering vaccines. Most inactivated vaccines require a booster before protection is complete. The first time an inactivated vaccine is administered, the primary response occurs. This is fairly short-lived, not very strong, and is predominantly comprised of IgM. The response seen after a booster vaccination is called the secondary response or anamnestic response. This is much stronger, of longer duration, and is primarily composed of IgG (Rude, 1990; Tizard, 1992). T cells follow a similar pattern of an anamnestic response shown in Figure 14.2. If the booster is given too early, the anamnestic response does not occur; and if too much time elapses before the booster is given, it acts as an initial dose, not as a booster. With most modified live vaccines (with the exception of most BRSV vaccines), the primary vaccination also stimulates the secondary response without needing a booster since the virus or bacteria is replicating in the animal.

Adverse Reactions

Adverse reactions are a potential risk with any vaccination. However, dairy cattle appear to have a higher risk of postvaccination reactions than other cattle. These reactions fall into three primary types (Jewett & Armstrong, 1990; Johansen et al., 1990; Mueller & Noxon, 1990; Rude, 1990; Schuster et al., 1991; Rietschel and Brade, 1992; Tizard, 1992; Henderson & Wilson,

1995; Ridge et al., 1996; Forsthuber et al., 1996; Sarzotti et al., 1996).

1. IgE and the release of granules from basophils and mast cells mediate immediate hypersensitivity. This reaction is seen within minutes of vaccination and often begins with shaking or sweating. The majority of these animals will respond to epinephrine.
2. Delayed hypersensitivity is mediated by an antibody–antigen complex attaching to complement and the ensuing activation of the complement cascade. The resultant reaction may occur locally or systemically. The reaction may be delayed as the complexes form and the cascade begins and subsequent by-products begin to exert their effects. The signs are similar to immediate hypersensitivity and treatment is epinephrine.
3. One of the more common reactions seen in dairy cattle has been associated with the endotoxin and other bacterial components found in most gram-negative vaccines. Currently, there are no requirements for monitoring or reporting the amount of endotoxin found in cattle vaccines, and the level of endotoxin may vary dramatically between vaccines and serials of the same vaccine. Furthermore, the potency of endotoxin varies among different gram-negative bacteria. This is seen primarily in Holsteins due to some genetic predisposition and can be seen following the administration of any gram-negative bacterin. The signs seen vary depending on the farm's or individual's sensitivity to gram-negative bacterial components. The number or severity of the gram-negative fractions in the vaccination program administered simultaneously are also instrumental in causing these reactions. As a general rule, no more than two gram-negative vaccines should be administered on the same day to dairy cattle. These adverse reactions include:
   a. anorexia and transient decreases in milk production
   b. early embryonic deaths
   c. abortions
   d. gram negative bacterial (endotoxic) shock, requiring fluxinin or ketoprofen, steroids, antihistamines, and fluids

Summary

Designing a vaccination program involves a good history of the individual farm as well as a basic understanding of the immune system. The vaccines chosen should have good solid efficacy studies (as well as effectiveness and efficiency studies if possible) to ensure that the product can fulfill the needs of the farm or ranch. Management decisions may be made that do not maximize the potential of the product chosen, and realistic expectations of all products should be well explained to the producer before they are used. The owner should be involved in the vaccine decision-making process, and all of the information on the product should be shared.

The establishment of good baseline immunity of replacement heifers and the foundation of a vaccination program can have dramatic effects on the health and profitability of the herd and needs to be well planned.

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15

Management of Dairy Calves from Birth to Weaning

Sheila M. McGuirk

Abstract

Calves represent the future of the dairy and, as such, management during the critical stage from birth to weaning is critical to the development, health, productivity, and profitability of the future replacement heifers. The perinatal period is one of the most vulnerable times in the life of the calf, and attention to the details of calving and calf viability immediately after birth can prevent the losses commonly encountered in the first 48 h of life. New concepts in colostrum management not only reinforce the importance of colostral immune factors on calf health but also emphasize its longer term impact on intestinal, ruminal, and metabolic development as well as the impact on endocrine status, growth, productivity, and survival. Nutritional management concepts have changed and are now appropriately focused on targeted growth with components and delivery systems that promote welfare, performance, and future production. Whether young calves are housed in individual or group pens, important principles of housing management can be applied to insure the health and welfare of preweaned calves. Routine health maintenance practices, preventive health screening, and effective treatment protocols should be strategically integrated into the management of young calves to optimize health, minimize stress, cost, and the possibility of doing harm.

Introduction

Management of the dairy calf from birth to weaning is intensive, challenging, and costly, but the investment in labor, feed, housing, equipment, bedding, medications, and vaccinations at this critical stage is an investment in the health and productivity of the future replacement heifers. The average cost of raising a dairy heifer calf from birth to movement into a group pen after weaning is U.S.$326 or U.S.$5.31/day from a Wisconsin study (Zwald et al., 2007). While the investment into replacement heifer rearing has little chance of economic return prior to the first lactation, it is apparent that early life management has long-term affects on the health, productivity, and profitability of replacement dairy heifers. Rather than adopt a least cost approach to managing dairy calves, this chapter will investigate practices that reduce calf raising costs by improved perinatal survival, reduced morbidity, and earlier weaning, and that enhance long-term profitability through internal herd growth, improved reproductive performance, and milk yield of replacement dairy heifers.

Management of the dairy calf from birth to weaning presents many challenges, and is the focus of this chapter because of its importance in both short- and long-term outcomes of health, performance, productivity, and future profitability of replacement dairy heifers. Variables that affect calf survival at birth will be identified so that proper procedures can be put in place to identify and monitor high-risk calves. New concepts in colostrum management will be discussed that not only reinforce the importance of colostral immune factors on calf health but also emphasize its long-term importance in intestinal and ruminal development, the metabolic and endocrine status of growing heifers, growth, productivity, and survival. The nutrient status of calves from birth

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to weaning not only determines whether dairy calves can meet target goals for growth but also impacts health and long-term development. The nutritional management and housing concepts that are important to the health and productivity of calves from birth to weaning will be addressed. Routine health maintenance practices, procedures, preventive health, and treatment protocols will be discussed, integrated and presented strategically to optimize health, minimize stress, cost, and the possibility of doing harm.

Perinatal Care

The perinatal period, defined as the first 48 h of a calf's life, is one of the most vulnerable times in the life of the calf. Careful attention to the details of calving and calf viability immediately after birth can prevent death. Defined protocols and consistently executed actions that remove the calf from the calving environment, administer quality colostrum, attend to navel care, and identify the high-risk calves will have an immediate and future impact on health, growth, productivity, profitability, and longevity in the herd.

Calf death rates in the perinatal period are a growing concern with 4.3% reported for pasture-based (Mee et al., 2008) and 8.0% for confinement-based systems (Silva del Rio et al., 2007), respectively. While 10% of perinatal calf deaths occur prior to calving, the majority occurs during and after parturition (Mee, 2004) and may be preventable. As half of perinatal deaths are attributed to dystocia or abnormal calf presentation (Collery et al., 1996; Lombard et al., 2007; Gundelach et al., 2009; Mee, 1999), management of the factors that can reduce the risk for dystocia and that can be controlled is important. Cow factors, including age at first calving, body condition score at calving, genetic merit of the sire for direct perinatal mortality, use of sexed semen, nutrition, observation, supervision, and appropriate calving assistance, while not the subject of this chapter, deserve consideration (McGuirk et al., 1999; Meyer et al., 2001; Ettema & Santos, 2004; Pryce et al., 2006; Berry et al., 2007; Mee et al., 2008; Mee, 2008a). Assisted or not, all perinatal deaths should be recorded by calf, age at birth, calving assistance level, and cause of death. Calving assistance or dystocia is not a cause of death, and all unexplained calf deaths should be investigated by postmortem examination. Some perinatal calf deaths that occur after unassisted deliveries or without apparent cause have been attributed to prolonged labor, low birth weight, abnormal gestational length, and placental dysfunction (Bittrich et al., 2002, 2004; Berglund et al., 2003; Johanson & Berger, 2003; Kornmatitsuk et al., 2004; Gundelach et al., 2009). Improving perinatal dairy calf losses requires focused attention on determining a cause, identifying calves at risk, making changes, and implementing procedures that reduce risks.

Supervision of newborn calves by persons knowledgeable, capable, and caring must be a priority to improve survival and the health of newborn dairy calves. Premature calves (less than 270 days gestation), calves born after prolonged or forceful deliveries, calves born from pharmacologically induced labor, calves with premature placental separation, or twin calves are the most likely to be slow to respond and require immediate attention. Knowledge of a timeline for expected newborn calf behaviors and vital sign parameters as shown in Table 15.1 (Mee, 2008b) can provide the best basis for the first assessment of calf vitality. Reduced vigor at birth is attributed to combined abnormalities of metabolic and respiratory acidosis (Szenci, 1982, 2003), but portable analyzers of blood pH and lactate concentration adapted for calf-side testing are neither readily available nor adequately tested. In lieu of laboratory testing, a modified APGAR (appearance, pulse, grimace, activity, respiration) scoring system shown in Table 15.2 that correlated well with blood lactate levels (Sorge et al., 2009) can be used to assess the vitality of newborn calves. Low-scoring calves by APGAR (Sorge et al., 2009) or other vitality screening methods (Szenci, 1982) are considered high risk. The high-risk calf requires immediate action and, later, should be readily identified by chalk marking, ear tag identifiers, or pen markers (Fig. 15.1) that relegate it to heightened observation and regular screening for

Table 15.1. Timeline for newborn calf behavior and vital signs (adapted from Mee, 2008b)

Time	Expectations of a normal dairy calf
Birth	Haircoat covered with placenta but not discolored
Within minutes	Responds to stimulation with vigorous head shake
Less than 5 min	Head righting
5 min	Sitting in sternal recumbency
Within 15 min	Making attempts to stand
Within 1 h	Standing
Within 2 h	Suckling
Within 1 h	Rectal temperature stable at 102–103°F (39–39.5°C)
Within 1 h	Heart rate 100–150 bpm
Within 1 h	Respiratory rate 50–75 breaths/min primarily from chest movements and no open-mouth gasping

Table 15.2. A modified APGAR scoring system to assess newborn calves (Sorge et al., 2009)

Reaction tested	Score 0	Score 1	Score 2
Cold water on the head	No reaction	Reduced or delayed reaction	Lifting, shaking of head
Squeezing between claws	No reaction	Withdraws foot slowly, weakly	Immediate and strong withdrawal
Mucous membrane color	White or blue color	Pale, grayish, or blue-tinged	Pink, moist
Respiratory pattern	Not breathing	Irregular frequency and pattern of breathing	Regular frequency and pattern of breathing

disease (discussed later in this chapter). Newborn vitality assessment scores should be entered into the calf's permanent record and can be used later for analysis of calf management, the score's relationship to future calf health or heifer performance, and for making individual calf decisions.

Procedures must be clearly established, the methods thoroughly understood, and equipment readily available in the calving area for newborn calf resuscitation to be practical and effective. Identified by flaccid muscles, lack of responsiveness to stimulation, or bluish discoloration of the mucous membranes, these calves should be placed onto a low platform—bag of shavings, low platform, cart, or table. Place the head and neck over the edge of the raised area to allow 10–15 s for postural drainage of fluid from the mouth and nose. Pull the calf back onto the platform and attempt to place it in a sitting position. Vigorously rub the topline of the calf with a dry towel, beginning at the tail and moving forward toward the head. At the head of the calf, dry the nose, clearing additional mucus or fluid from the nares. Towel stimulation is then directed to the ears and eyelids. For calves still not breathing at this time, finger pressure can be applied to the muzzle between the two nostrils (Fig. 15.2a), inside the nostril across the nasal meatus (Fig. 15.2b), or the trachea can be compressed (Fig. 15.2c) from side to side to further stimulate respiratory efforts or coughing. Cold water poured onto the head or into the ear of the calf can also be used to stimulate a gasp reflex that triggers breathing (Uystepruyst et al., 2002). Nasal fluid

Figure 15.1. A chalk mark on the head (a), a nylon tie attached to the ear tag (b) or a colored clothes pin attached to a calf hutch (c) identify high-risk calves that need special care and monitoring.

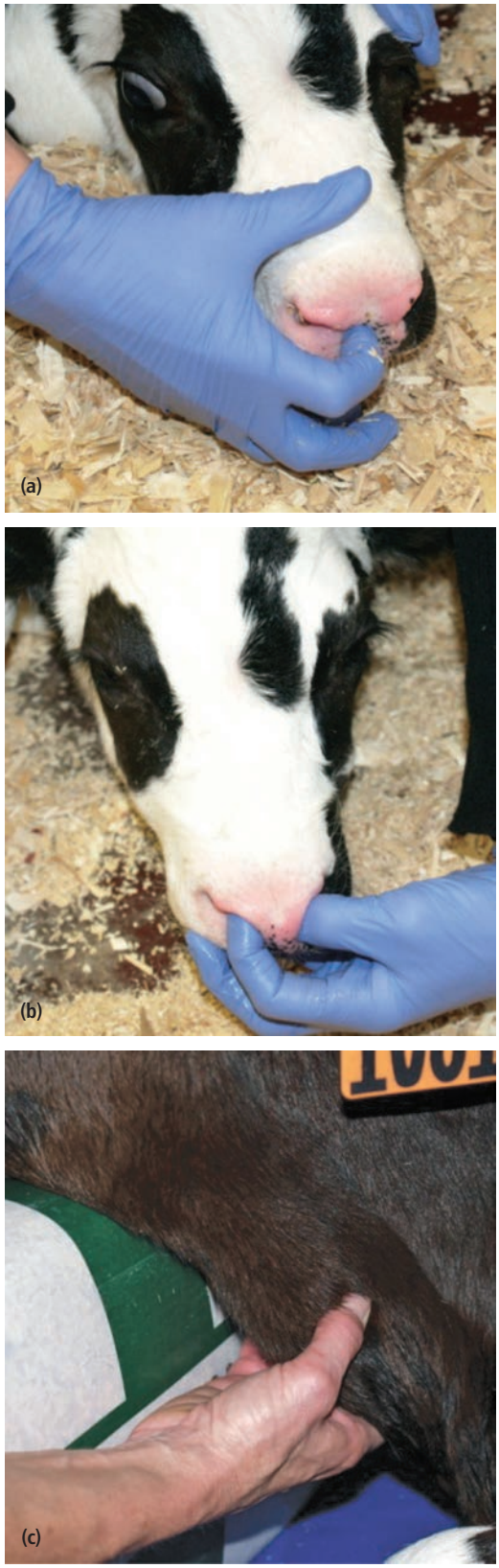

Figure 15.2. Pressure applied directly to the muzzle (a) or across the nasal septum inside the nose meatus inside the nose (b) may stimulate breathing in the newborn calf. Tracheal compression (c) can induce a cough reflex followed by respiratory efforts.

suction can be useful at this time if the calf begins to breathe and fluid or fluid sounds are impairing the respiratory effort. While oxygen therapy may be useful and intranasal administration of oxygen to newborn calves has been shown to improve respiratory function (Bleul et al., 2008), the equipment required and the necessity for prolonged application has limited its use to controlled clinic or hospital settings. Widely used in practice, the benefit of pharmacologic respiratory stimulation in calves is limited or even contraindicated (Mee, 1994; Garry & Adams, 1996). Despite some transient apparent improvement, it is believed that doxapram reduces cerebral blood flow, while increasing the cerebral oxygen requirement and consumption (Plunkett & McMichael, 2008). Atropine (0.01 mg/kg) and epinephrine (0.1 mg/kg 1:10,000) may also have transient benefits for cardiopulmonary support, especially for calves with bradycardia. Rapid administration of 3–4 mL/kg of hypertonic (7.5%) saline solution (HYSS) over 5 min has also been a successful method for resuscitation of calves (Garcia, 1999; Nagy, 2009). After HYSS administration, 2 qt of warm water is administered. What fluid is not consumed by suckling is administered by esophageal feeder. The warm water is necessary to complement the HYSS administration and is an adjunct in maintaining or restoring normal body temperature of the calf. A small, 5-g bolus of dextrose (10 mL of 50% dextrose solution) can be administered if there is concern for hypoglycemia. With pharmacological interventions completed, the calf should be placed in sternal recumbency and moved from side to side, with encouragement to stand. Passive limb motion improves thermoregulation through muscle activity.

Removing newborn calves from the maternity area or calving pen within 15 min of birth or before standing attempts are initiated should be the goal of all dairies 24 h a day. With repeated standing attempts by the calf that stays in the adult cow environment, there is significant risk for fecal-oral transmission of pathogens. Calving cows increase fecal coliform shedding by 10^4 to 10^7 colony forming units/gram of feces near parturition (Pelan-Mattocks et al., 2000). Even without fecal-oral inoculation, the newborn umbilical cord may be another potential site for infectious agents to gain access to calves left in the adult cow environment. Calves left in the calving area carry maternity pen flora to the calf housing area when they are moved. While many dairies provide newborn calves with an intermediate holding area for warming, drying, navel care, assessment, identification, colostrum feeding, and administration of other newborn calf protocols, it may be beneficial to take a dry calf directly to the individual clean, dry, deeply bedded pen, where it will be housed until weaning. Communal, warm

calf holding areas are not recommended unless calves are taken there immediately after birth. These areas are easily contaminated with maternity pen flora from the skin of calves that have lingered in the calving pen. Prolonged stays in interim warm housing may also make it more difficult for newborn calves to adapt to environmental temperatures outside of the thermoneutral zone of 55° (12.7°)–68°F (20.0°C) (Gonzalez-Jimenez & Blaxter, 1962; Scibilia et al., 1987) or 59° (15°)–77°F (25°C) (Schrama et al., 1993; Arieili et al., 1995) when they are moved. Deep straw bedding and calf jackets provide the nesting and insulation needed for cold calf housing.

The umbilical cord of most calves ruptures spontaneously during or shortly after calving. Spontaneous rupture is preferred to manual rupture that sometimes occurs during assisted deliveries. After rupture, the umbilical blood vessels contract and are retracted into the abdomen, actions that protect from blood loss and infection. Navel care of calves is controversial, and there is limited research data to provide guidance. Less than 30% of dairies indicate that they treat navel infections (USDA, 2009), which are consistent with its reported occurrence in 5%–15% of calves (Virtala et al., 1996). Navel infections (omphalitis) have been consistently blamed for about 2% of preweaned dairy calf deaths (USDA, 2009) and in surviving calves may represent a source of intermittent bacterial showering with subsequent fever and spread of infection to lungs, joints, intestinal tract, or brain. While navel problems are not usually that common, infections can have severe consequences and are preventable.

While navel disinfection is a common management practice on most dairies, of greater importance is having spontaneous rupture of the umbilical cord after the delivery of a calf into a clean, well-bedded calving area with the immediate removal of that calf to an equally well-managed calf pen or hutch where it receives 3–4 qt (2.8–3.8 L) of good quality colostrum. Without a history of navel problems (infections or hernias occur in less than 5% of calves), focus on hygiene of the calving area, immediate removal of the calf to a clean calf pen, and colostrum administration. If more than 5% of calves develop navel problems, improvement may be noted when navel disinfection is performed early and repeated once or twice at 12-h intervals. Whether the navel is dipped or sprayed, avoid chemical irritation of the skin by covering only the umbilical cord with disinfectant and not the skin around the navel.

Navel disinfectants for which there are some published studies showing efficacy are 1%, 2%, and 7% iodine and 0.5% chlorhexidine (Mee, 2008b). In our hospital, we add distilled water to 25 cc of Nolvasan solution (2% chlorhexidine) to make 100 mL of navel disinfectant. Individual application cups are filled with 2–4 oz (60–120 mL) dipping solution, which are discarded after the final dip for that calf. With a spray bottle, it may be easier to maintain a clean solution that can be used on several calves. Irritating solutions like sodium hypochlorite (bleach) should not be used for navel disinfection.

Colostrum

Colostrum management has a critical impact on the health and survival of dairy calves from birth to weaning (McEwan et al., 1970; Brignole & Stott, 1980; Blom, 1982; Gay, 1984; National Animal Health Monitoring System, 1993; Wells, 1996). Beyond the immediate benefit to calf survival and preweaning health, colostrum also has long-term implications on growth rate and feed efficiency (Nocek et al., 1984; Robison et al., 1988), reproductive efficiency (Waltner-Toews et al., 1986e; Faber et al., 2005), milk production (DeNise et al., 1989; Faber et al., 2005), and longevity in the herd (Robison et al., 1988). In addition, colostral components support the growth, development, and function of the small intestine, rumen development, and are responsible for other metabolic and endocrine effects (Hammon & Blum, 2002; Sauter et al., 2004).

Colostrum provides immune factors, hormones, growth factors, vitamins, minerals, and other macronutrients, but it is the immune factor, immunoglobulin G1 (IgG1), that has served as the basis for tests that judge the success of herd colostrum management programs or adequate transfer of immunity to an individual calf. IgG1 transfer from the colostrum to the newborn calf is considered adequate when calves less than 1 week of age reach a minimum serum IgG1 concentration of 1000 mg/dL (Gay, 1984; Tyler et al., 1996; Wells, 1996; Weaver et al., 2000). For optimum calf health on most dairies, IgG concentrations greater than 1000 mg/dL may be desirable. Serum IgG1 concentration less than 1000 mg/dL serves as the basis for the condition called failure of passive transfer (FPT), which has been correlated with economic loss from disease susceptibility, impaired performance, and mortality (Gay, 1983; Hancock, 1985; Robison et al., 1988; DeNise et al., 1989; Wells, 1996). In large calf studies, 19%–41% of calves have FPT (National Animal Health Monitoring System, 1993; USDA, 2009) and, as the proportion of calves with FPT in a herd increases, so does the risk for mortality (Hancock, 1985).

To reach the minimal serum IgG1 concentration, calves should ingest 150–200 g of immunoglobulin (Besser et al., 1991; Hopkins & Quigley, 1997; Tyler

et al., 1999a). Whether maternal colostrum, a colostrum replacement (CR), or a combination of CR and supplement product is fed (Quigley et al., 2002; Swan et al., 2007; Smith & Foster, 2007), an adequate immunoglobulin mass must be presented to the calf when absorption efficiency is optimal. The IgG concentration in colostrum is variable (Pritchett et al., 1994; Morin et al., 1997; Swan et al., 2007; Chigerwe et al., 2008). High-quality colostrum, which has a minimum IgG concentration of 50 g/L is needed to deliver an adequate immunoglobulin mass in 3–4 qt of colostrum (Besser et al., 1991), but the availability of accurate cowside tests to determine this level of colostrum quality is limited (Pritchett et al., 1994; Chigerwe et al., 2005, 2008). The hydrometer (colostrometer) is acceptable as a colostrum quality screening test but overestimates colostrum IgG concentration and requires that colostrum be cooled to the instrument-recommended temperature (Chigerwe et al., 2008). Colostrometer results showing poor quality colostrum (yellow or red level exposed during flotation) accurately indicate that 4 qt will not deliver an adequate immunoglobulin mass. To be more confident that the colostrum IgG concentration is at least 50 g/L, select colostrum with a colostrometer reading of 70 g/L or higher (Chigerwe et al., 2008). While routine colostrum IgG concentration screening may result in rejection of 20%–30% of colostrum samples tested, it is very likely to demonstrate adequate colostrum quality in many first lactation cows (Tyler et al., 1999b; Chigerwe et al., 2008) and cows that produce more than 2 gal of colostrum (Chigerwe et al., 2008). It can also be used to find other management practices that minimize the amount of colostrum rejected for being poor quality.

The many factors that affect colostrum quality have been recently reviewed (Godden, 2008) and some, like breed, age of the dam, and season of calving are not under management control. Several other practices, like dry cow mastitis prevention, nutrition management, vaccinations, and dry period length can be changed to maximize the supply of good quality maternal colostrum on the dairy. Colostrum premilking should be avoided and fresh cows, particularly high-producing ones, should have colostrum harvested within 2–4 h of parturition (Moore et al., 2005). Colostrum pooling should be avoided (Weaver et al., 2000) unless it is necessary for colostrum pasteurization.

Another measure of colostrum quality is the level of bacterial contamination. Recent studies indicate that bacterial counts greater than 100,000 cfu/mL in colostrum (McGuirk & Collins, 2004) interfere with immunoglobulin absorption (James et al., 1981; Poulsen et al., 2002; Johnson et al., 2007; Elizondo-Salazar & Heinrichs, 2009), and may be a potential source of infection from infectious agents such as *Mycobacterium avium* subsp *paratuberculosis*, *Mycoplasma bovis, Salmonella* spp, and other intestinal pathogens (Streeter et al., 1995; Steele et al., 1997; Walz et al., 1997). Colostrum contamination can be avoided by proper udder preparation of fresh cows prior to milking colostrum, use of clean, sanitized milking equipment to harvest colostrum and, after collection, refrigerated storage of the colostrum in clean, sanitized containers unless it is fed immediately (Stewart et al., 2005). Refrigerated colostrum that is not fed within 2 days should be discarded. Addition of the preservative potassium sorbate to achieve a 0.5% final concentration in colostrum can extend the refrigerated life of colostrum to 6 days (Stewart et al., 2005; Godden, 2008). Colostrum cultures that provide standard plate counts along with the identification and quantification of bacterial subpopulations (Jayarao et al., 2004; McGuirk & Collins, 2004) will determine the need for closer management of colostrum harvest and storage.

Heat treatment of colostrum is the best method to reduce bacterial contamination (Godden et al., 2006; Johnson et al., 2007; Elizondo-Salazar & Heinrichs, 2009). Batch pasteurization of colostrum at a temperature of 140°F (60°C) for 60 min is recommended and has been shown to reduce the concentration of pathogenic bacteria, maintain IgG activity, preserve the desired fluid consistency of colostrums, and result in superior IgG levels in recipient calves (Godden et al., 2006; McMartin et al., 2006; Johnson et al., 2007). In a study that utilized batch heat treatment of colostrum at 140°F for only 30 min, there was improved serum IgG concentration in calves with heat-treated colostrum, but high bacterial concentration did not interfere with IgG absorption (Elizondo-Salazar & Heinrichs, 2009). Bacteria in colostrum multiply rapidly so pasteurization should occur as soon after collection as possible. Once pasteurized, the shelf life with refrigeration is 8–10 days (Godden, 2008). The effectiveness of colostrum pasteurization should be established with testing and maintained through the process of storage and delivery to the calves.

With clean colostrum that has at least 50 g/L IgG concentration, 3.75–5 qt (3–4 L) of colostrum will deliver the desired 150–200 g mass of immunoglobulin to the newborn calf. When the colostrum immunoglobulin mass is not known, it is recommended that 10%–12% of body weight be fed at the first feeding within the first 4 h of life (Godden, 2008). It is essential to hand-feed colostrum to dairy calves because natural suckling results in very high rates of FPT from delayed sucking (Edwards & Broom, 1979) and ingestion of an inadequate volume (Besser et al., 1991). Dairy producers are mixed in their preference for the route of colostrum administration (USDA, 2009). Suckling a nipple bottle, using an esopha-

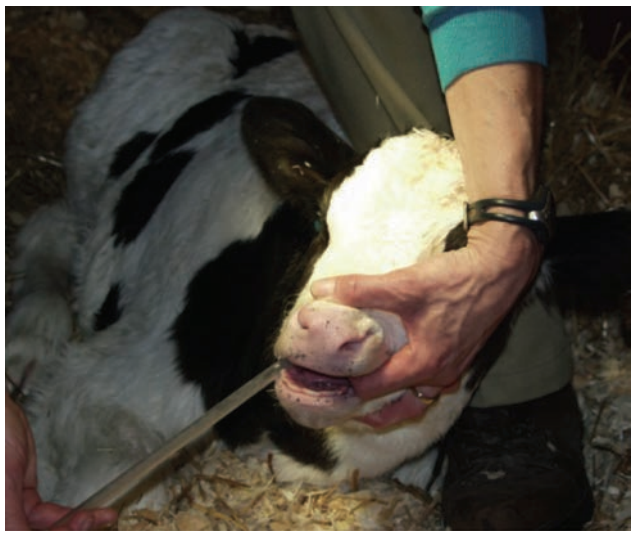

Figure 15.3. The picture illustrates the proper position of the calf's head for introduction of the esophageal feeder. With the nose below the level of the ears, the esophageal feeder must be introduced slowly to induce swallowing and proper placement in the esophagus.

geal feeder, or a combination of methods can provide acceptable rates of passive transfer in calves, provided that sufficient volume is fed (Adams et al., 1985; Besser et al., 1991; Kaske et al., 2005). For calf feeders that use an esophageal feeder to administer colostrum, prior training and consistent adherence to protocols is necessary. It is preferable that calves stand to have the esophageal feeder introduced but, at a minimum, they should be in a sitting position with the neck slightly flexed to position the nose below the ears (Fig. 15.3). When using an esophageal feeder to administer colostrum, 4 qt should be fed (Godden et al., 2009b). Use an esophageal feeder with capacity for the full 4-qt colostrum volume so that the tube only has to be introduced once. For dairies that feed a smaller volume of colostrum, suckling is the preferred method for colostrum administration (Godden et al., 2009b), but a minimum volume of 3 qt (2.8 L) is recommended. Uninterrupted nursing increases the likelihood that calves will suckle 3 qt, so utilize 3-qt bottles for colostrum administration.

Feeding fresh or refrigerated maternal colostrum is preferred by most dairies over feeding frozen colostrum or CR products (USDA, 2009), but it is advantageous to have a colostrum backup plan to be implemented in the face of short colostrum supplies, during heightened infectious disease control periods or for calves required to have negative antibody titers for select dairy markets. Colostrum with all of its immune, nutritional, growth, and developmental components is believed to be preserved with effective refrigeration for 7 days. Immunoglobulins, selected nutritional, growth, and developmental factors may be preserved with frozen colostrum storage for up to 1 year, provided the freezing temperature is maintained and the conditions of storage do not dehydrate or expose the colostrum. Thawing and rewarming stored colostrum should avoid temperatures over 140°F (Godden, 2008). Of recent interest and recognized importance in the developing immune system of the calf is the cellular component of colostrum (Donovan et al., 2007; Reber et al., 2008a,b), which is not likely to remain viable after heat treatment (Godden, personal communication) or frozen storage.

Limiting colostrum feeding to a single, large-volume meal creates an opportunity to store extra colostrum. With a progressive decrease in the efficiency of immunoglobulin absorption over time (Besser et al., 1985), additional colostrum feedings may be of little to no benefit to the calf. Subsequent feedings of unpasteurized colostrum can increase the chance for disease transmission by exposing the calf to more than one colostrum donor or by inadvertently feeding colostrum with heavy bacterial contamination (McGuirk & Collins, 2004). With a single colostrum meal, the only dietary change faced by the calf occurs between the first and second feedings and before a consistent feeding pattern is established. There may be some intestinal, metabolic, and endocrine developmental advantages to continued colostrum feeding for 3 days (Hammon & Blum, 1997, 1998, 2002; Blättler et al., 2001), but a health and performance benefit with prolonged colostrum feeding has not been established (Franklin et al., 2003).

Without stored colostrum, CR products present an alternative to feeding maternal colostrum. The available powdered commercial CR products contain a minimum of 100 g of bovine immunoglobulin derived from colostrum, whey, or plasma that are designed to be mixed with water and administered to newborn calves. As with maternal colostrum feeding, the expectation is that recipient calves reach the minimum 1000 mg/dL serum IgG concentration, indicative of a successful transfer of immunity. To date, the CR studies that have focused either on achieving this minimum serum IgG concentration or a serum IgG concentration comparable to calves fed maternal colostrum as outcomes have shown disappointing results (Mee et al., 1996; Quigley et al., 2001; Smith & Foster, 2007; Swan et al., 2007) unless higher doses were fed (Quigley et al., 2001; Jones et al., 2004; Foster et al., 2006; Godden et al., 2009a). These studies provide evidence that, similar to maternal colostrum, calves fed CR products require a minimum 150–200-g dose of IgG for successful passive transfer. As a means of controlling infectious disease transmission through

maternal colostrum, the benefit of feeding a CR product for Johne's disease control has been demonstrated (Pithua et al., 2009).

The success of a dairy herd's colostrum management program is established and monitored by testing. In herd-based testing for passive immunity, individual calf test results determine the proportion of calves that fall below the stated goal or cut-point. Established as the gold standard for quantitative IgG1 measurement, the radial immunodiffusion test has not been successfully adapted for herd-based testing as it is costly and time inefficient. Serum total protein measurement by refractometer is suitable for farm use, has been validated as a measure of the immunoglobulin status of calves (Naylor & Kronfeld, 1977; Pfeiffer et al., 1977; Tyler et al., 1996), is correlated with disease and mortality rates in calves (Naylor et al., 1977), and has been used to establish cut-points that can be applied for herd-based testing (Tyler et al., 1996). Herd-based testing of dairy calves less than 1 week of age using 5.5 g/dL serum protein concentration as the cut-point and an alarm level set at 20% has been described (McGuirk & Collins, 2004). With a minimum suggested test sample size of 12 calves, results showing 0 (0%), 1 (8.3%), or 2 (16.7%) calves out of 12 with a serum total protein concentration less than 5.5 g/dL indicate good colostrum management. If 4 or more calves out of 12 (greater than 20% of the tested calves) have a serum total protein concentration less than 5.5 g/dL, FPT is a herd problem that must be fixed. Consistently performed, reported, and discussed, herd-based testing for FPT provides an opportunity for constructive feedback, management changes, and useful incentives that benefit calf health and performance.

Nutritional Management

The nutritional management of the dairy calf to weaning is labor-intensive and costly, but done well, has an important positive impact on health, growth, development, and future milk production. Only 2%–4% of the body weight of the newborn calf is adipose tissue, the largest proportion of that being brown adipose tissue or thermogenic fat (Alexander et al., 1975). Body protein reserves are also low in newborn calves, leaving it dependent upon the colostrum feeding, not just for immune factors but also for the nutritional, growth, and organ development factors. After feeding colostrum, the calf must rely on dietary intake to supply calories from protein, carbohydrates, and fat that are required for maintenance, growth, generation of body heat, and immune system function. Key aspects of dairy calf nutrition are the composition and amount of liquid feeds, the starter feed offered, and the availability of water. Current concepts are changed and appropriately focus on targeted growth with components and delivery systems that promote welfare, performance, and future production. For a more complete discussion of dairy calf nutrition, readers are referred to a recent review (Drackley, 2008).

There is a growing consensus among scientists, industry specialists, and producers (15th American Dairy Science Association Discover Conference on Calves, Roanoke, VA; Dairy Calf & Heifer Association Gold Standards, www.calfandheifer.org) that, from birth to weaning at 56–60 days, the dairy calf should double its birth weight. By these standards, a Holstein calf with a 90 lb birth weight is 180 lb at 56 days of age and has achieved an average daily gain of 1.6 lb/day (0.73 kg/day). It is estimated that feeding 1.8–2.5 lb (0.82–1.14 kg) of milk solids/day allows calves to reach the targeted weight and grow 4–5 in. (10.2–12.7 cm) in height by weaning. Between 49 and 56 days, the liquid feed can be decreased by 50% or fed once daily, allowing starter intake to increase. Calves consistently consuming 2 lb (0.91 kg) of calf starter per day are weaned. Traditional milk or milk replacer feeding at 8%–10% birth weight will not meet targeted calf nutrition goals.

The approach to feeding dairy calves that provides liquid feed in an amount and composition that more closely mimics natural conditions is termed accelerated growth, intensified nutrition, or biologically appropriate growth. Using this approach, milk feeding rates are almost double the traditional feeding rates, giving calves 1.5% of body weight as milk solids during the first week of life, followed by 2% of body weight from week 2 until the week before weaning, when one liquid feeding per day is dropped (Stamey et al., 2005; Drackley, 2008). Compared to conventional milk replacer feeding programs, accelerated milk replacer feeding programs can deliver expected growth rates of 1.3–1.8 lb/day (0.59–0.82 kg/day), compared to 1.1–1.3 lb/day (0.50–0.59 kg/day) for conventionally fed calves from days 0 to 42 (Drackley, 2008). A program intermediate between the conventional and accelerated programs delivers an expected growth rate of 1.2–1.4 lb/day for the first 42 days and claims fewer digestive upsets and less of a weaning slump (Hill et al., 2006; Drackley, 2008). In addition to enhancing growth, improving the nutritional status of 2 to 3-week old calves benefits the immune status, health, age to breeding, and future milk yield (Drackley, 2005; Ollivett et al., 2009; Van Amburgh et al., 2009).

Milk replacers are fed on most dairies but whole milk, salable, nonsalable, or a combination of liquid feeds make up the liquid diet of calves before weaning. The nutrient content of the liquid diet must be matched to the desired calf growth rates, fed with consistency to

Table 15.3. The nutrient composition delivered per gallon is shown for three different milk diets

	Protein (%)	Fat (%)	Total Solids
Whole milk	27	30	12.7% 0.285 lb (129 g) protein/gal 0.317 lb (143 g) fat/gal
Milk replacer	20	20	11.4% 0.190 lb(86 g) protein/gal 0.190 lb (86 g) fat/gal
Milk replacer	28	20	15% 0.333 lb (151 g) protein/gal 0.238 lb(107 g) fat/gal

minimize chances for digestive upset and adjusted for cold or warm weather feeding. For the first 2–3 weeks of life, the calf's digestive enzymes are inefficient or unable to digest nonmilk proteins or polysaccharides such as starch, so nonmilk proteins should be avoided (Drackley, 2008). Table 15.3 compares the protein, fat, and total solids composition of whole milk and two different milk replacer formulations showing the nutrient composition delivered in 1 gal of liquid feed.

The energy requirement for thermoneutral maintenance of a 100 lb (45 kg) is about 0.7 lb (325 g) of milk solids, or 5.7 lb (2.6 kg) of whole milk (about 2.6 qt or 2.5 L) (Drackley, 2008). The same calf would require about 0.8 lb (380 g) of milk replacer (about 3.2 qt or 3.0 L as fed) for maintenance because milk replacers are lower in fat than whole milk. The protein requirement of 0.1 lb (30 g) per day for maintenance of a 100 lb (45 kg) calf is not substantially altered by cold or heat stress. Protein requirements are mostly for growth. On average, 0.4 lb (188 g) of protein is required for every 2.2 lb (1 kg) of body weight gain, which would require about 0.6 lb (250–280 g) of crude protein intake from the milk replacer (Drackley, 2008). Body deposition of protein for growth depends upon dietary protein intake, provided that there is sufficient energy to use the protein. Milk replacers that provide less than 22% crude protein make it difficult to achieve targeted growth goals before weaning (Van Amburgh & Drackley, 2005).

The feeding adjustments that are needed for temperatures out of the thermoneutral zone can be calculated (National Research Council, 2001) and are most critical for calves in the first 2 weeks of life or for those not yet consuming 1.0 lb of starter. Cold weather adjustments are more clearly established than the changes required for heat stress but, under both conditions, feeding adjustments and additional supportive care should be provided. Ready access to fresh water, sheltered housing, and appropriate bedding is essential. At temperatures under 58°F (14.4°C), increase the volume of milk fed at each feeding or, preferably, provide a third feeding to calves being fed a traditional volume of milk or milk replacer per day. The third feeding, though more labor-intensive, is best positioned to divide the longest interval between feedings. Alternatively, the solids content of the milk replacer can be increased or supplemental fat can be added (Jaster et al., 1992). Increasing the total solids to a maximum of 18%, provided that this is done gradually, 1%–2% at a time, or is fed continuously from birth to weaning during cold weather is reported can be an alternative to three times a day feeding. The development of new feeding systems that allow free access to low-bacteria count milk or milk replacer offers calves the opportunity to compensate for cold and reach enhanced growth targets before weaning.

Beyond feeding calves to meet targeted growth goals, producers must feed to promote calf health. Consistency in the delivery of calf feeds prevents digestive disturbances such as bloat, diarrhea, and enterotoxemia. Changes in feeding time, milk, or milk replacer temperature, total solids composition, feeding pattern, nipples, bottles, buckets, or additives can be stressful, change gastric emptying, or alter intestinal motility. Healthy calves can make small adjustments to feed changes while stressed, cold calves, calves incubating infection, or calves in contact with diseased calves become ill.

With the increasing utilization of whole milk to feed calves, its bacterial quality, nutrient composition, and supply must be carefully managed. Pasteurization can provide consistent control of the pathogenic organisms (Stabel, 2001; Stabel et al., 2004; Jorgensen et al., 2006; James & Scott, 2009) provided that the quality of incoming milk, the pasteurizer effectiveness, and the postpasteurization handling of milk is optimal. Total solids, milk pH, and ethanol coagulation test monitoring are suggested as practical farm tests for monitoring the quality of whole milk fed to calves (Moore et al., 2009). To control waste milk supply and quality, inclusion of the use of salable milk from the bulk tank or the addition of solids from milk replacer, whey proteins, or fat supplements have been suggested (James & Scott, 2009).

Antibiotics and other milk or milk replacer additives with purported health and growth claims should be used on the basis of need, potential for benefit, and cost

weighed against any potential negative outcomes. Many calf milk replacers contain antibiotics and most, but not all, studies comparing medicated and nonmedicated milk replacers show some benefit in weight gain, feed efficiency, or health parameters (Waltner-Toews et al., 1986a,b; Braidwood & Shenry, 1990; Sivula et al., 1996; Donovan et al., 2002; Berge et al., 2005, 2009). Minimizing or eliminating the use of antibiotics in calf feeds requires excellent colostrum management to provide enhanced immunity, enhanced disease detection, and specifically targeted therapeutic intervention (Berge et al., 2005, 2009). In consideration of adding a coccidiostat (decoquinate, lasalocid), probiotics (*Lactobacillus* spp., *Bifidobacterium* spp., and others), prebiotics that provide substrate for growth of beneficial bacteria (oligofructose, mannanoligosaccharides, and others), immunoglobulins (IgG, IgY), botanicals, or others, look for evidence of significant efficacy, have zero tolerance for potential to do harm, and recognize that additives will not forgive poor management, an environment with a heavy exposure to disease-producing organisms, or a calf made susceptible to disease by inadequate colostrum, vaccination overload, or inadequate nutrition.

To promote early and increasing intakes, calf starter should be added to the diet of newborn calves within the first 3 days of life. Presentation and formulation affect palatability. Fresh starter should be offered daily in amounts that result in limited refusal. Increasing the feeding rate by half-pound increments and the use of textured starters formulated with easily fermentable ingredients promotes intake (Franklin et al., 2003; Drackley, 2008). The addition of a coccidiostat (decoquinate, monensin, lasalocid) is recommended for improved feed efficiency and health, provided that delivery and access insures consumption of an appropriate level (Hill et al., 2005; Drackley, 2008). Have an accurate measure of 2 lb (0.91 kg) of starter to serve as the basis for weaning decisions.

Water, always an essential nutrient, is most important for calves living outside their critical temperature range, being fed a diet high in total milk solids or when they are scouring (Kertz et al., 1984). The water requirement, even at birth, cannot be provided solely through the liquid feed. Water should be introduced into the diet within the first 3 days of life and, ideally, should be available at all times. When cold temperatures limit access to water, it should be presented warm twice daily. Calves that receive water immediately after the milk or milk replacer feeding wait for water before lying down. Calves provided water between feedings may be less likely to leave warm bedding to drink water and therefore drink less. At all temperatures, water intake promotes starter intake (Kertz et al., 1984).

Housing

Calf housing can have an important impact on the health and performance of dairy calves. Removed from the calving area within 10 min of birth, calves are given a preweaning home that provides dry shelter, clean bedding for nesting when temperatures are below 58°F (14.4°C), appropriate conditions to minimize heat stress when temperatures are above 68°F (20.0°C), and a physical space in which a calf is comfortable exhibiting its normal behaviors. From birth to weaning, calves spend approximately 75% of the day lying down (Panivivat et al., 2004), making bedding management extremely important in minimizing the fecal-oral transmission of pathogenic organisms that cause diarrhea. Bedding depth distances calves from organisms shed in the feces while providing additional comfort. Adequate nesting occurs in bedding with enough depth and loft to completely cover the legs when the calf is lying down (Lago et al., 2006). Straw is the bedding of choice for young calves housed in conditions below 55°F (12.7°C). Other bedding types can be considered when calves are within the thermoneutral zone, but the finer the bedding type, the more likely that the bedding will retain manure and urine and, therefore, the faster the rise in bedding bacterial counts. Finer bedding materials like sand and granite fines are dirtier and are associated with more scours than coarse bedding materials like long wheat straw and wood shavings (Panivivat et al., 2004).

Generally considered an advantage for disease control (Waltner-Toews et al., 1986e; Svensson et al., 2003; Svensson & Liberg, 2006) and individual calf monitoring, calf hutches or individual calf pens have been the standard in the dairy industry (USDA, 2009). Calf hutches have many positive aspects for calf health when managed well, but they can present seasonal challenges under conditions of extreme heat or cold. Outdoor calf hutches that are positioned to prevent calf-to-calf contact for disease control can also provide three different thermal zones (back of the hutch, front of the hutch, or outside of the hutch) from which the calf can choose to locate (Brunsvold et al., 1985). Calf barns that house calves' individual calf pens must be managed well for comfort, protection from cold stress, air quality within the pen, filling, and emptying patterns (Lunborg et al., 2005; Lago et al., 2006). Elevated pens can put calves at higher risk for chilling drafts or exposure to aerosolized fecal pathogens if placed over waste removal flush systems. From birth to 2 months, 32 sq ft (3 m^2) of space is the minimum recommended for calves in individual pens (Hoffman & Plourd, 2003; Stull & Reynolds, 2008), and there should be 15% more pens than calves at maximum occupancy to

provide time to clean, disinfect, and rest pens between successive calf occupants (Heath, 1992).

The interest in group housing for preweaned dairy calves is growing as automated feeding systems become more available and studies show behavioral advantages, higher solid feed intakes, increased weight gain, and reduced weaning setbacks for calves raised in pairs or small groups (Warnick et al., 1977; Richard et al., 1988; Kung et al., 1997; Chua et al., 2002; Faerevik et al., 2006; Svensson & Liberg, 2006). With some recognized advantages, group housing puts young calves at risk for higher morbidity and mortality rates (Waltner-Toews et al., 1986c,d). Successful management of young dairy calves in group housing requires a colostrum feeding program that consistently delivers documented results of adequate immunity, a group size that is small (Chua et al., 2002; Svensson & Liberg, 2006; Assié et al., 2009), pens that provides a minimum of 28 sq ft (3 m^2) of space per calf (Hoffman & Plourd, 2003; Stull & Reynolds, 2008), increased milk allowance or ad-libitum feeding, established health monitoring protocols, individual calf handling equipment, a stable population of calves, and all-in, all-out management of group pens (Sivula et al., 1996; Pedersen et al., 2009).

The flooring under individual or group calf pens may be dirt, gravel, concrete, expanded wire, or slatted wood. Porous surfaces should be well suited to filter excreta and moisture away from the calf during pen occupancy and be scraped, removed, and restored between successive pen occupants. A gravel base of 10–15 in. (25.4–30.5 cm) with tile at the bottom allows fluids to drain quickly down and out of the barn. A thin layer of the pea gravel can be removed and replaced when the pens are cleaned after each use. If disinfectants are used, they must be suitable for uptake by porous surfaces. Nonporous floor surfaces require more bedding to distance the calf from excreta and moisture as well as to provide adequate insulation and nesting when temperatures are below 55°F (12.7°C), but they are easier to clean and disinfect between successive pen occupants. Concrete floors are necessary for housing that provides in-floor heat and should be sloped away from the feeding area. Whatever calf pen surface is chosen, the surface and bedding must protect calves from thermal stress, minimize risk of slipping, injury or trauma, provide comfort for normal lying behavior, and keep calves clean.

Control the number and survival time of microorganisms in the calf environment by taking refused milk, milk replacer, water, and starter away from the calf housing area. Increase pen size, have fewer solid barriers surrounding calf pens, lower calf pen temperature, and bring more outside air into indoor calf pens to lower aerosolized bacterial counts in calf housing (Lago et al., 2006; Nordlund, 2008). Prevent contact between calves in individual pens, lower calf density in group pens, and increase time between successive occupants of individual and group pens to improve infectious disease control. Solid panels between calf pens that have extensions on the front of the pen to prevent calf-to-calf contact are advisable for calves in individual pens, but keep the front and back of pens as open as possible for improved air quality.

Continuous flow housing systems put individual calves at high risk for disease (Sivula et al., 1996; Pedersen et al., 2009) and farms at risk for endemic enteric and respiratory disease in preweaned calves. Being able to completely empty, clean, disinfect, and rest the calf barn or large areas of individual pens at least once each year is a significant opportunity to maximize calf health and performance by lowering the population of resident microorganisms within the calf environment.

Health Care

Newborn Calf Care

Close observation of the calf during and immediately after delivery is described in the perinatal care section of this chapter. Before any standing attempts have been made, calves are removed into a clean, dry, and deeply bedded calf pen or holding area where the newborn calf care protocols are implemented. Examination of the navel looks for persistent bleeding, unusual size, appearance, or structures. Hygiene is the emphasis of navel care, but navel disinfectants, when used as described in the perinatal care section, are applied at this time.

Colostrum feeding is initiated as soon as the newborn calf demonstrates a suckle reflex but no later than 4 h after birth. The administration of an oral vaccine for scours prevention necessitates a delay in colostrum administration as the colostral antibodies may interfere with the production of an effective immune response by the calf (Van Zaane et al., 1986). No colostrum feeding delay is required for calves that receive an oral antibody product like First Defense, Bovine Ecolizer, Colimune, Barguard, or others for enhanced scours protection. These antibody products must be administered, however, in the same narrow window of time after birth during which antibody absorption efficiency is still present. Details of colostrum management are described in the colostrum section of this chapter.

Vaccinating Calves

The goals of any vaccination protocol established for calves from birth to weaning should be to provide optimal immunity to the agents or diseases that are most

likely to be encountered. Calves need to be protected when they are at most risk for disease challenge by vaccines that are safe, effective, and cost-efficient. Vaccines with any potential to do harm should be avoided.

The most common infectious problems of preweaned calves are diarrhea and respiratory disease. Important, but less common, are navel infections and neonatal septicemia that can result in infection of the joints, brain, kidney, or any other body organ system. The calves at greatest risk of developing diarrhea are less than 2 weeks of age, with peak onset typically occurring between 5 and 9 days of age (Waltner-Toews et al., 1986a; Waltner-Toews et al., 1986b; Curtis, 1988; Sivula, 1996). The first episode of respiratory disease in dairy calves occurs in calves less than 3 weeks of age (Sivula et al., 1996; Virtala et al., 1996). The ingestion and absorption of immune factors in colostrum obtained from healthy, vaccinated cattle is the primary way to provide young calves with effective immunity to these important diseases.

The conventional view that calves cannot be vaccinated effectively while they have circulating maternal antibodies from colostrum has changed (Woolums, 2007; Chase et al., 2008). Typically, parenteral vaccinations have not been recommended for calves because measurable antibody responses to the vaccine could not be demonstrated in the face of maternal antibodies to that specific disease agent. This approach left calves vulnerable because maternal antibody decline was not synchronous for all disease agents and, even with the persistence of maternal antibodies at a level sufficient to block vaccination, there was little protection against some disease challenges. More recently, it has been found that measuring the serum antibody response to a vaccination does not give a complete picture of its effectiveness as selective cells, like cytotoxic T cells (CD8+ T cells), gamma delta T cells, and memory B cells also play important roles in antigen-specific immunity to selective disease agents (Endsley et al., 2003). Even without measurable antibody responses, some modified live virus vaccinations like bovine viral diarrhea virus (BVDV), bovine respiratory syncytial virus (BRSV), and bovine herpesvirus 1 (BHV-1) can elicit T-cell responses in young calves that prime them for subsequent vaccination or offer protection in the face of challenges (Brar et al., 1978; Kimman et al., 1989; Endsley et al., 2003; Chase et al., 2008). New approaches to vaccinating calves from birth to weaning have emerged, and there is continued interest in developing safe ways to circumvent maternal antibody interference. This should not undervalue the importance of maternal colostrum nor should it encourage off-label or untested use of current vaccines. With new vaccine developments in adjuvant technology, epitope modification, and nonconventional methods of administration, vaccination of calves should address a need and not just because we can.

The use of intranasal modified live, temperature-sensitive parainfluenza type 3 (PI3) and infectious bovine rhinotracheitis (IBR) virus combination in newborn calves is utilized for the presumed specific and nonspecific protection against respiratory disease that can affect calves in the first few weeks of life. While the intranasal route for vaccinating 1 week and older calves has the benefit of inducing rapid immunity that can circumvent potential interference from circulating maternal antibodies (Kimman et al., 1989; Bryson et al., 1999; Woolums et al., 2004; Vangeel et al., 2007, 2009), the effectiveness of newborn calf vaccination needs to be established.

Dehorning Calves

There are several methods that can be used to dehorn calves. Topical application of a caustic chemical paste is suitable for calves less than 1 week of age. Gas or rechargeable electric dehorners apply heat to cauterize the blood supply to the horn tissue and can be used in calves up to 4 weeks of age. Hot iron dehorners utilize electric or gas-filled irons to cauterize the skin at the base of the horn and can be used in calves up to 12 weeks of age. Tube or spoon dehorners use a sharpened metal tube to remove the horn producing skin around the horn bud and are suitable for calves up to 4 weeks of age. Gouge or Barnes-type dehorners remove horns up to 4 in. long along with skin around the base of the horn and, therefore, can be used in older calves or calves that develop horn scurs after the initial dehorning procedure. Dehorn calves early, but do not add it to the stress of weaning and, regardless of the dehorning method used, appropriate restraint, preparation, and pain control are necessary (Duffield, 2007).

For dehorning by application of caustic chemical paste, clip the hair to expose the horn buds of the newborn calf and, with the calf well restrained and hands protected by gloves, apply a thin layer of paste that completely covers the horn bud. Protect the eyes of the calf during application of the paste. This method is not suitable for calves kept in group housing.

For calves that are dehorned with gas, electric, or hot iron, tube, or gouge dehorning methods, good restraint is essential, and sedation can provide the ideal restraint. In the hands of experienced people, sedation is not necessary, and good calf restraint coupled with expertly administered local anesthesia is acceptable. The use of an injectable sedative administered about 5–10 minutes before dehorning simplifies the introduction of a local anesthetic injected at each of two sites per horn.

Administration of a nonsteroidal anti-inflammatory drug at the time of the local nerve block provides extended pain control following dehorning (Duffield, 2007). Sedated and locally blocked, dehorning young calves is efficient and precise. Using a hot iron method to cauterize the skin at the base of the horn, apply it for just enough time to cause a color change in the skin. There are no bleeders to be pulled or cauterized with this method, and calves are usually standing within 20 min to an hour and are ready to drink milk by the next feeding. Because of the sedation, calves should be watched closely for 1–2 h following dehorning and no food or water should be offered until the sedation is completely worn off. Calves that are depressed, head-pressing, or have an abnormal head tilt for more than 2 h should be examined by a veterinarian.

Screening Calves for Health Problems

At 7.8%, the mortality rate of dairy calves between 48 h of age and weaning (USDA, 2009) exceeds the Dairy Calf & Heifer Associations Gold Standard of <5% (www.calfandheifer.org). Scours and respiratory problems are responsible for the majority of preweaned calf deaths at 56.5% and 22.5%, respectively (USDA, 2009). Improved detection and earlier implementation of effective treatment protocols can lower mortality rates but requires that a regular health screening process is implemented. Detecting illness in young calves on the basis of reduced appetite for liquid feed or a dull attitude may not find problems, particularly respiratory disease, at an early stage when treatment is most effective. Appetite-based detection of pneumonia fails to identify as many as 50% of affected calves and, when identified, is typically 4–5 days after onset (Virtala et al., 1996; Quimby et al., 2001). Daily screening to find sick calves or those that require further examination can be an efficient and effective process that, when timed appropriately, is conducted from outside of the pen. Soon after a milk or a milk replacer feeding, when the majority of calves are lying down or just before the next feeding while calves are still lying are times that the abnormal behavior or appearance of sick calves are best detected. Calves that remain standing or still appear to be drinking long after a feeding when the majority of calves are lying down should be marked for further examination. Again, just prior to a later feeding, when the majority of calves are still lying down, those that are standing, exhibit abnormal standing or sleeping posture, are unresponsive to voices, have abdominal fullness, or have hair standing erect should also be evaluated further.

A calf health scoring chart available at http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_health_scoring_chart.pdf can serve as a basis for the examination details needed to find calves to be treated for diarrhea or respiratory disease. From outside the pen, abnormal fecal consistency or appearance, Figure 15.4 can be noted and quiet calves can be screened for respiratory disease by looking for abnormal nasal discharge, ocular discharge, ear position, or spontaneous coughing. With moderate to severe ocular or nasal discharge, abnormal ear position or head tilt coupled with repeated spontaneous coughing, respiratory disease is likely. Calves with two or more abnormal signs should be considered for treatment. Inside the pen, the additional examination parameters of rectal temperature, navel palpation, and tracheal compression to induce coughing can be performed by the examiner wearing disposable gloves. Again, fecal consistency should be noted from either a fresh sample in the bedding or on the thermometer, but gentle rectal stimulation with a lubricated and gloved finger will induce defecation in most calves.

Treating Calves for Health Problems

The most important part of the calf diarrhea treatment protocol is rehydration. In addition to regular milk or milk replacer feedings and *ad libitum* access to water, calves with diarrhea as shown in Figure 15.4a or 15.4b require 2 qt (1.9–3.8 L) of supplemental fluids with electrolytes. Oral electrolyte solutions should be mixed in warm water as directed by the label. To correct dehydration, electrolyte-containing fluids are an addition to and not a substitution for regular milk, milk replacer, and *ad libitum* water. Continued feeding during diarrhea is recommended but may not be beneficial if force-feeding is required (Quigley et al., 2006). More frequent, smaller milk feedings may be required as calves with fecal consistency shown in Figure 15.4a,b may need a minimum of 10 qt (9.5 L) of fluid per day of diarrhea supplied by a combination of milk feedings, oral electrolyte solution, and water. Access to water is essential when electrolyte-containing fluids are administered to diarrheic calves.

If examination of the calf with diarrhea reveals a temperature greater than 103°F (39.4°C) or lower than 100°F (37.7°C), if the calf is dull, off feed, drinks slowly, stands with an arched back, or has a significant amount of blood in the feces, a 3-day course of antibiotics is advisable (Constable, 2004; McGuirk, 2008). The selection of a therapeutic antibiotic is based on fecal culture results or the appropriate gram-negative bacterial spectrum (Fecteau et al., 2003; Constable, 2004). Nonsteroidal anti-inflammatory drug administration may be of additional benefit but should be repeated only with persistence of an abnormal temperature (>103°F or <100°F) or other signs of systemic illness. Other additives to the

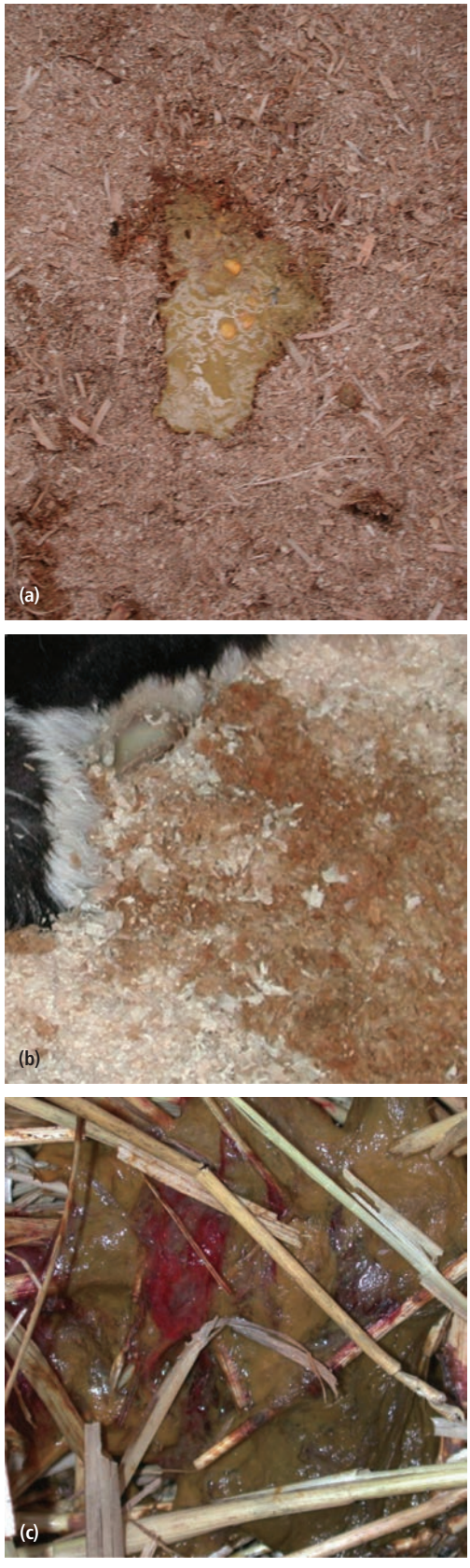

Figure 15.4. Calves with abnormal fecal consistency shown in 4a and 4b require rehydration therapy. Abnormal feces with blood (4c) may increase concern for salmonellosis and therefore be an indication for antibiotic treatment.

liquid feed that promote normalization of the intestinal environment can be beneficial but should be done with evidence of success and close monitoring for consistency in total solids and sodium levels in the feed. Deep, dry bedding and blankets may be needed for sick calves when temperatures are below the thermoneutral zone.

Respiratory disease should be treated when calves receive a score of 5 points or more using the Calf Respiratory Health Scoring Chart available at http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_respiratory_scoring_chart.pdf. Alternatively, calves with a single sign of respiratory disease detected from outside the pen and a fever equal to or greater than 103°F (39.4°F) should be treated with antibiotics. Or, any calf that exhibits two or more of the signs of respiratory disease at the same time—cough, colored (white, yellow, blood tinged) nasal or eye discharge, drooping or twitching ears, or fever (<100°F or >103°F) should be given antibiotic therapy. The respiratory disease treatment course should be 5–6 days in length. One time or multiple-dose treatment protocols may be advised by your veterinarian based on testing (McGuirk, 2008), efficacy, and compliance. Nonsteroidal anti-inflammatory drug administration may be of additional benefit but should be given intravenously and repeated only with persistence of an abnormal temperature (>103°F; 39.4°C) and systemic illness. Supportive care with additional oral fluids, deep, dry bedding, or blankets can be beneficial. It is very important that calves with respiratory disease be treated early and effectively, so that they are cured before they move into postweaning housing.

For persistent or severe herd problems with diarrhea or calf respiratory disease, diagnostic testing may be useful. As previously described (McGuirk, 2008), the most useful diagnostic information comes from live, untreated calves among the age-group at risk. For a calf diarrhea problem with 5 days as the typical day of onset, fecal samples from 6 untreated 4- to 5-day old calves, regardless of fecal consistency, are submitted for rotavirus, coronavirus, *Salmonella* spp. and *Cryptosporidium parvum* diagnostic testing, for example. If any calf is shedding *Salmonella* spp., it is considered significant, and the antimicrobial susceptibility pattern from the isolate can guide that portion of the herd's treatment protocol. When more than 30% of the sampled calves are shedding any one of the other potential fecal pathogens—rotavirus, coronavirus, or *C. parvum*—attempts should be made to identify and minimize the source of exposure. For respiratory disease problems in calves, diagnostic testing can be used to guide treatment decisions, elucidate a cause or both, as previously described (McGuirk, 2008). Selecting from untreated calves in the age-group at risk, a population of six or more affected

calves is sampled using nasal swabs (used for antibiotic susceptibility patterns), deep pharyngeal guarded swabs (pathogen isolation and antibiotic susceptibility patterns), or bronchoalveolar fluid samples (cytologic evaluation and potential pathogen isolation). While herd protocols are best guided by diagnostic testing in live animals, postmortem examinations should be conducted on a regular basis to find opportunities for improved calf care. Not to be underestimated, the labor and time requirements for health management alone of calves from birth to weaning is significant and has been estimated at 0.5 full-time equivalent for each 150–200 calves in a Wisconsin study (Zwald et al., 2007). Empowered with time and support, calf health protocols are implemented by workers with knowledge, understanding, and problem solving skills (Vaarst & Sørensen, 2009).

Records

The importance of implementing a comprehensive calf record system cannot be overemphasized. Management practices based on calf data consistently gathered, entered, analyzed, and monitored is used to make informed decisions, identify trends, analyze problems, test solutions, and improve profit. Readers are referred to a detailed review of the main aspects of implementing a record system, using recorded data to making decisions and analyze trends (Bach, 2008).

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16

Nutritional Management of Dairy Heifers

Pedro Melendez Retamal

Abstract

Heifers should be bred at 15 months of age to calve around 24 months of age, weighing between 550–625 kg at calving with a height and body condition score of 1.30 m and 3.25–3.75, respectively. Consequently, they should be grouped strategically in lots of five heifers between weaning and 3 months old, lots of 15 heifers between 3 and 6 months old, and lots of different sizes until 7 months of pregnancy. Strategies for feeding management should consider environmental conditions (ambient temperature and humidity) as well as profit.

Introduction

Dairy heifers should be bred at 13–15 months old to calve at 22–24 months old. This can optimize profit of dairy operations since milk production and longevity can be maximized. To reach these goals, nutrition and feeding management must be adequate so that the growing curve is satisfactory. Either low or high daily gains are undesirable. Small heifers produce less milk and are more likely to experience dystocia. Accelerated growers may become overconditioned with reduced lifetime and milk yield, more dystocia, and high incidence of metabolic diseases. Furthermore, excessive energy intake before puberty can affect the development of parenchyma of the mammary gland, reducing the number of alveolar cells and milk synthesis. This is because body weight has no linear relationship with growing rate; therefore, parenchyma of the mammary gland may be altered with fat deposition before the ductal system is developed if excessive energy is consumed before puberty (National Research Council, 2001).

Grouping Strategies

Because weaning is a stressful process for the dairy calf, it is highly recommended to house the weaned calf in a small lot with no more than five calves per group until they are 3 months old. After this time, calves can be grouped in lots of 15 calves per group until 6 months of age. From 6 to 15 months of age they should be housed in groups of variable numbers according to circumstances of each farm. Groups should be homogeneous and balanced. Heifers 10–12 months old should be handled as a prebreeding group; those of 13–15 months as the breeding group where reproductive management begins. Reproductive strategies for heifers are discussed elsewhere. As soon as a heifer is diagnosed and confirmed pregnant at 45 days after breeding, it should be grouped in an early pregnant lot until 5 months of gestation. From 5 to 7 months of gestation it should be housed as a late pregnant group. At 7 months of pregnancy it should be moved to the prepartum transition group until parturition.

Weight, Height, and Body Condition Score

Holstein heifers should weigh between 550 and 625 kg at calving (1210–1375 lb). The heifer's height and body condition score should be 1.30 m (54 in.) and 3.25–3.75, respectively. As a result, the average daily gain from birth to parturition should be 0.7–0.8 kg/day (1.54–1.8 lb/day).

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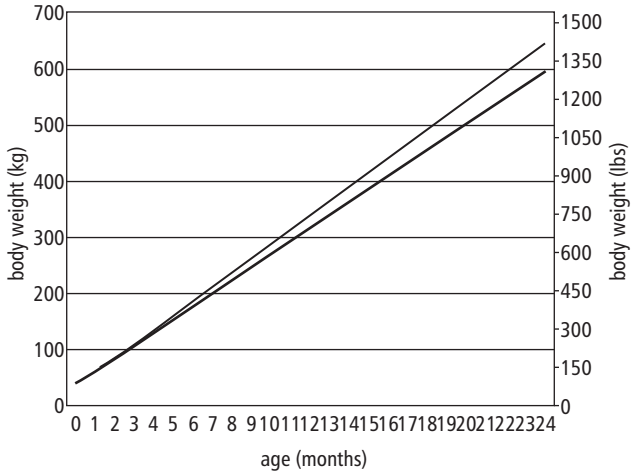

Figure 16.1. Upper and lower range of Holstein heifer body weight.

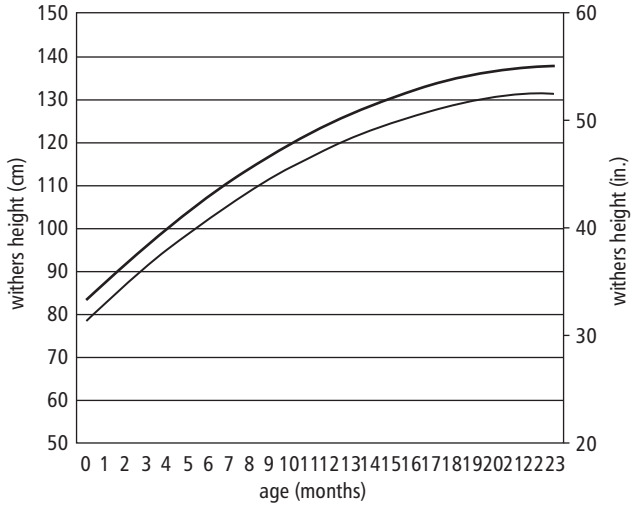

Figure 16.2. Upper and lower range of Holstein heifers withers height.

These growth rates should be partitioned as 0.8 kg/day (1.8 lb/day) from 3 to 10 months of age (prepuberty) and 0.7 kg/day (1.54 lb/day) from 10 to 24 months of age (postpuberty) (Gardner et al., 1988; Hoffman & Funk, 1991). In Figure 16.1 and Figure 16.2, upper and lower body weight and withers height for Holstein heifers is shown.

Energy and protein requirements for growth in heifers are calculated from the energy and protein deposited in tissues during growth (National Research Council, 2001). To reach the goal of an average daily gain of 0.7–0.8 kg/day (1.54–1.8 lb/day), it must be assumed the hair coat of a heifer is clean and dry, it is fed free-choice, it is healthy, and it is raised in a thermoneutral environment (20°C, 68°F). Consequently, nutrient requirements should be adjusted for environmental and management conditions. Feed intake is inversely related to environmental temperature. The adjustment of dry matter intake due to either intake depression caused by high temperatures or intake increment caused by cold weather may be required. Dry matter intake should be increased when temperatures are below 15°C (59°F). However, factors such as mud, cold, or frozen water, and feed can negatively impact dry matter intake.

The National Research Council (1989) offers adjustments for net energy (NE) of maintenance when environmental temperature is 1°C above or below 20°C. For each 1°C above or below 20°C, the value of 0.0007 should be subtracted or added to the constant 0.086 in the NE for maintenance equation 0.086 ($BW^{0.75}$). Failure to provide increased dietary energy during cold weather can result in lower average daily gains (0.1–0.2 kg/day) compared with heifers fed in neutral thermal conditions. When severe cold stress is experienced, energy requirements may not meet minimum levels of dietary effective NDF to maintain proper rumen activity. Consequently, improvement of the environment is the key to maintaining adequate growing curves.

Heifers under grazing conditions can meet expected growing rates. However, forage availability is the key to reaching these objectives. Forage is limited during summertime and extreme cold weather. As a result, a supplemental program (silage, concentrates) when forage is restricted is required. Supplemental magnesium (magnesium oxide) is often required under lush, fertilized, cool season pastures; otherwise, grass tetany may be a problem.

If heifers older than 1 year have access to good quality forage, it may be the only feed required for this stage of growing. In addition, they should have access on a free-choice basis trace minerals and major minerals (Ca, P, Mg, Cl, Na, K, and S). If average daily gain is not reached, energy and protein supplements should be fed as needed (grains). In general, heifers should express their first estrus at 9–12 months of age with 280–300 kg (615–660 lb) of body weight.

Heifers should be moved to the prepartum group at 7 months of gestation. They should be fed a transition diet with good-quality forages, intermediate amount of concentrate (1% BW), with similar ingredients used in lactating diets. They do not need anionic salts since milk fever is uncommon in first-lactating cows. Sodium and potassium should be restricted in order to avoid udder edema development.

Overconditioned heifers should be avoided (body condition score [BCS] > 3.75). They have higher incidence of dystocia because of small pelvic development and fatness of birth canal. However, underfed heifers also will require more calving assistance and may have a higher incidence of stillborns and mortality rate at calving than normal-sized heifers. National Research Council requirements (2001) for heifers at different stages is shown in Table 16.1.

Table 16.1. Nutrient requirements of growing Holstein heifers to obtain daily gain needed to reach a mature body weight of 680 kg according to National Research Council 2001

	6 m, 200 kg, BCS 3.0, to calve at 24 m age	12 m, 300 kg, BCS 3.0, to calve at 24 m age	18 m, 450 kg, BCS 3.0, to calve at 24 m age
Dry matter intake predicted by model (kg)	5.2	7.1	11.3
Dry matter intake predicted by model (lb)	11.4	15.62	24.9
Energy			
ME (Mcal/day)	10.6	16.2	20.3
ME (Mcal/kg)	2.04	2.28	1.79
ME (Mcal/lb)	0.93	1.03	0.82
Protein			
Metabolizable protein (g/day)	415	550	635
Diet % MP	8.0	7.7	5.6
Rumen degradable protein (RDP) (g/day)	481	667	970
Diet % RDP	9.3	9.4	9.6
Rumen undegradable protein (RUP) (g/day)	176	226	88
Diet % RUP	3.4	2.9	0.8
% RDP + % RUP (crude protein)	12.7	12.3	9.4
Fiber and carbohydrate			
ADF %, min	30–33	30–33	30–33
NDF %, min	20–21	20–21	20–21
NFC %, max	34–38	34–38	34–38
Minerals			
Absorbable calcium (g)	11.3	15	13
Dietary Ca %	0.41	0.41	0.37
Absorbable phosphorus (g)	9.1	10.6	13
Dietary P %	0.25	0.23	0.18
Mg %	0.11	0.11	0.08
Cl %	0.11	0.12	0.10
K %	0.47	0.48	0.46
Na %	0.08	0.08	0.07
S %	0.2	0.2	0.2
Co (mg/kg)	0.11	0.11	0.11
Cu (mg/kg)	10	10	9
I (mg/kg)	0.27	0.3	0.3
Fe (mg/kg)	43	31	13
Mn (mg/kg)	22	20	14
Se (mg/kg)	0.3	0.3	0.3
Zn (mg/kg)	32	27	18
Vitamin A (UI/day)	16,000	24,000	36,000
Vitamin D (UI/day)	6000	9000	13,500
Vitamin E (UI/day)	160	240	360
Vitamin A (UI/kg)	3076	3380	3185
Vitamin D (UI/kg)	1154	1268	1195
Vitamin E (UI/kg)	31	34	32

Table 16.2. Example diets for heifers at 6, 12, and 18 month-old under confinement and grazing conditions

	6 m, 180 kg, BCS 3.0, (0,75 kg/day)	12 m, 300 kg, BCS 3.0, (0,75 kg/day)	18 m, 450 kg, BCS 3.0, (0,70 kg/day)
Diet under complete confinement (1)			
Grass silage	7.0	11.0	22.0
Alfalfa hay (17% CP)	1.4	0.5	0.5
Corn grain	0.5	2.0	1.75
Soybean meal, solv. 48% CP	0.3	0.2	0.2
Minerals plus vitamins	0.12	0.15	0.15
Diet under complete confinement (2)			
Corn silage	2.5	6.0	12.0
Oat silage	3.5	7.0	20.0
Alfalfa hay	1.5	0.5	—
Wheat millrun	1.0	2.0	1.0
Soybean meal, solv. 48% CP	0.15	0.25	—
Minerals plus vitamins	0.12	0.15	0.15
Diet under grazing conditions			
Grazing (ryegrass)	7.0	12.0	12.0
Grass silage (10% CP)	4.7	8.0	18.0
Alfalfa hay	1.0	—	—
Corn grain	0.35	1.5	1.5
Soybean meal, solv. 48% CP	0.15	—	—
Minerals plus vitamins	0.12	0.15	0.15

Herd Health Program for Raising Heifers

After weaning, calves are more susceptible to coccidia. Because clinical signs of this enteric disease become visible at the end of life cycle of the protozoa, pharmacological control should be established in early stages of the cycle, during which drugs are more effective. Consequently, medicated concentrate or minerals should be fed from the beginning. Drugs such as decoquinate at a rate of 0.5 mg/kg BW, lasalocid, or monensin at a rate of 1 mg/kg BW are recommended.

External and/or internal parasites can also be a problem. They may affect the growing rate of dairy heifers. Consequently, a consistent deworming program should be established as needed. In grazing heifers, deworming should occur as frequently as every 2 months. In confined systems, twice a year may be sufficient. However, egg fecal count may sometimes be required to monitor control and prevention.

Practical Considerations

Sample diets for growing heifers at different stages is shown in Table 16.2. Two sample diets under confinement and one sample diet under grazing conditions are offered.

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17

Management Strategies to Optimize Reproductive Efficiency in Dairy Heifers

Maria Belen Rabaglino

Abstract

Dairy producers can use various reproductive management programs to breed heifers. Synchronization of estrus or ovulation protocols not only should optimize pregnancy rates, but they must be practical to implement or the protocol will fail due to lack of compliance. Lifetime profit of dairy replacement heifers is maximized when heifers calve between 23 and 25 months of age. Therefore, in order to maintain genetic progress and maximize profitability, heifer breeding programs should include artificial insemination and calving to occur around 24 months. This chapter discusses reproductive management strategies that can be implemented to obtain an optimal calving age in dairy heifers.

Introduction

Replacement heifers represent the future milk production of a dairy herd. In order to sustain genetic progress and maintain an economic advantage from higher milk production, dairy producers should breed replacement heifers to proven sires used in artificial insemination (AI). For example, it has been reported that milk yield in daughters of AI-proven bulls was 366–444 kg greater compared to daughters bred to natural service (NS) sires (Overton & Sischo, 2005). Lifetime profit of dairy replacement heifers is maximized when heifers calve between 23 and 25 months of age (Head, 1992). However, actual calving ages of first calf heifers are greater than these on many herds. Thus, to maintain genetic progress and maximize profitability, heifer breeding programs should include AI and calving to occur around 24 months.

A commonly used reproductive management is AI at detected estrus from a spontaneous displayed estrus (Stevenson et al., 2008). Obviously, detection of estrus is crucial for effective reproductive management with AI (Ferguson & Galligan, 1993). Estrous detection efficiency is greater for dairy heifers because heifers express estrus more frequently and longer than lactating dairy cows (Nebel et al., 1997). However, in contrast to lactating dairy cows, time spent on estrous detection in heifers is limited, which can delay time of first AI and therefore increase age at first calving, associated with additional costs (Caraviello et al., 2006).This chapter discusses reproductive management strategies that can be implemented to obtain an optimal calving age in dairy heifers.

Estrous Synchronization Programs

The use of estrous synchronization programs optimizes the use of AI (Xu & Burton, 1999). Nevertheless, dairy producers must still rely on visual detection of estrus (Rivera et al., 2004).

Prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$)

By synchronizing a group of heifers with $PGF_{2\alpha}$, estral periods are concentrated within a 7-day window which helps improve estrus detection rate. Estrus could be synchronized in heifers when they reach breeding age through the use of a double injection of $PGF_{2\alpha}$ 11–14 days apart. Almost 100% of heifers should be at the right

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stage of the cycle to have a corpus luteum (CL) that responds to $PGF_{2\alpha}$, and therefore, most heifers display estrus within 7 days after the last injection (Jochle et al., 1982). However, this program requires the presence of a CL in the ovary, and it would not be effective in prepuberal heifers that are not cycling (Short et al., 1990; Patterson et al., 1992).

Progestogen Release Intravaginal Device

An alternative to improve synchrony of estrus is the administration of an exogenous progestogen for 7 days before $PGF_{2\alpha}$ treatment (Macmillan & Peterson, 1993). This ensures lysis or regression of the CL in response to $PGF_{2\alpha}$ because the progestogen exposure during 7 days allows for the development of a mature CL that will respond to the $PGF_{2\alpha}$ injection. The efficacy of an intravaginal insert, like the controlled internal drug release (CIDR, Eazi Breed™ CIDR® Pfizer Animal Health, New York, NY) insert during 7 days and an injection of $PGF_{2\alpha}$ on day 6 for synchronizing estrus was evaluated in postpartum beef cattle, peripubertal beef heifers, and dairy heifers (Lucy et al., 2001). In dairy heifers, a greater incidence (84%) of estrus was detected during the first 3 days of the breeding period compared with the $PGF_{2\alpha}$-treated heifers (57%), but pregnancy per AI (P/AI) during the first 3 days or during the 31-day breeding period were not improved for CIDR + $PGF_{2\alpha}$ compared with $PGF_{2\alpha}$-treated dairy heifers, although it was higher for beef cows and heifers. They concluded that the inclusion of the CIDR insert in combination with $PGF_{2\alpha}$ improved estrous synchronization rates relative to $PGF_{2\alpha}$ alone or control. Improved estrous synchrony led to greater P/AI for beef cows and beef heifers but failed to improve P/AI for dairy heifers.

Ovulation Synchronization Protocols

Importance of Ovulation Synchronization Protocols Compared with Estrous Synchronization Protocols

The use of AI to breed heifers is underutilized on many dairy farms, and the use of NS alone or in combination with AI is preferred (Hogeland & Wadsworth, 1995). A major limitation for use of AI in dairy replacement heifers is time and effort related with daily estrous detection (Erven & Arbaugh, 1987; Caraviello et al., 2006), especially if heifers are located at remote locations. Ovulation synchronization protocols that include timed AI (TAI), could allow for increased use of AI in heifers, avoiding the need for detection of estrus (Peeler et al., 2004).

In addition to the advantage that represents the increased use of AI for genetic improvement of the dairy, the implementation of an ovulation synchronization protocol also represents an economical advantage for dairy producers. Detection of estrus requires more labor per animal and therefore increases costs compared to a synchronization program on a dairy farm (Olynk & Wolf, 2008). In an overall economical analysis of reproductive management strategies used in U.S. commercial dairy farms, synchronization programs had a greater expected net present value than visual estrous detection programs (Olynk & Wolf, 2008). With a TAI management program, the time from puberty to conception is reduced, representing a lower negative cash flow due to a decrease in feeding cost, and higher positive cash flow from an increase in the lifetime profit of heifers (Moreira, 2009).

The "Problem" with Ovulation Synchronization Protocols in Dairy Heifers

The pattern of follicular development in heifers is different from that of lactating dairy cows (Sartori et al., 2004). Heifers have a faster rate of follicular growth (Pursley et al., 1997) and a higher frequency of three wave follicular cycles (Savio et al., 1988). Therefore, if an ovulation synchronization protocol is started with gonadotropin-releasing hormone (GnRH) at a random stage of the estrous cycle, failure to synchronize ovulation for TAI occurs. When the first GnRH injection is given at the beginning of a follicular wave, that is, at day 2 or 10 of the cycle, a dominant follicle is not present, resulting in a low ovulation frequency to the first GnRH injection (Moreira et al., 2000). If a new follicular wave emerges, luteinizing hormone (LH) receptors are not expressed in the granulosa cells of growing follicles during the first day of the follicular wave (Xu et al., 1995). This is prior to the time of deviation in follicular growth rates between eventual dominant and subordinate follicles that occur on average at 2.8 days after follicular wave emergence, when dominant follicle diameter is 8.5 mm and 7.2 mm for the largest subordinate follicle (Ginther et al., 1996).

In heifers with three follicular waves, approximately 57% of the estrous cycle is at a stage of follicular development that is not responsive to the first GnRH injection to cause an ovulation and initiate a new follicular wave. As a result of this lack of ovulation to the first GnRH injection (e.g., given at day 16 of cycle with a heifer having a 3-wave follicular cycle), the CL originating from the preceding spontaneous ovulation regresses before $PGF_{2\alpha}$ treatment. Thus, heifers would express estrus prematurely close to the time of the $PGF_{2\alpha}$ injection (Rivera et al., 2004, 2005).

It has been shown effectively that stage of the estrous cycle at which synchronization is initiated influences reproductive responses to the TAI protocol. If the protocol is initiated during an environment of high progesterone concentration (days 5–10 of the estrous cycle), then heifers have improved synchrony and fertility after TAI compared with heifers initiating the protocol during other stages of the cycle (Moreira et al., 2000).

Strategies to Avoid Expression of Estrus During TAI Protocol

Strategies have been developed to overcome expression of estrus during TAI protocols by synchronizing heifers in the early luteal phase, to avoid detection of estrus during the synchronization period. These strategies mainly focus on two components: (1) presynchronization prior to initiation of the TAI protocol and (2) supplementation of exogenous progesterone during the synchronization period to avoid premature ovulation and asynchrony of insemination.

Presynchronization Programs

It has been shown that the use of a double injection of $PGF_{2\alpha}$ administered 14 days apart for presynchronization before the initiation of the Ovsynch protocol 12 days after the second $PGF_{2\alpha}$ increase fertility in lactating dairy cows (Moreira et al., 2001). The program is known as the Presynch/Ovsynch. In dairy cows, this program increased pregnancy per TAI (P/TAI) by 17.3 percentage units at 72 days compared with cows receiving Ovsynch without presynchronization (Moreira et al., 2001).

In dairy heifers, the application of a GnRH injection 7 days before the onset of the 6-day Co-Synch 48-h TAI protocol has been evaluated (Rivera et al., 2006). These authors hypothesized that with the GnRH injection before the TAI protocol, an environment of high progesterone concentration due to ovulation of a dominant follicle and production of CL would occur. Nevertheless, proportion of heifers displaying estrus before the scheduled TAI and mean day of estrous expression during the protocol did not differ between the application of GnRH for presynchronization or not. This fact was attributed precisely to the higher frequency of three follicular waves and more rapid turnover of follicles in dairy heifers. Pregnancy per TAI at 30 days did not differ between treatments (44% for no presynchronization vs. 49% for presynchronization). The authors concluded that presynchronization with an injection of GnRH 7 days before the onset of a 6-day Co-Synch 48-h TAI protocol failed to improve synchronization response in randomly cycling dairy heifers.

Supplementation of Exogenous Progesterone During the Synchronization Period

In a study by Rivera et al. (2005), the proportion of heifers submitted to TAI was evaluated in heifers synchronized with the 6-day Co-Synch 48-h protocol with the inclusion of a CIDR insert (6-day Co-Synch 48-h + CIDR) compared with the 6-day Co-Synch 48-h protocol without a CIDR insert. Pregnancy per TAI did not differ between both groups (29% for the group without the CIDR insert and 32% for the group with a CIDR insert). In this experiment, P/TAI was profoundly affected by variation among herd AI technicians. However, as an interaction between treatment and technician was not detected, the main effects of treatment on experimental end points were valid. One of the main objectives of this study was to evaluate if the inclusion of the CIDR insert between the first GnRH injection and the $PGF_{2\alpha}$ injection would suppress estrus without affecting fertility. Results showed that none of the heifers receiving the CIDR insert displayed estrus during the protocol before scheduled TAI, whereas 24% of heifers when the CIDR insert was not included expressed estrus 4.5 ± 0.4 days after the first GnRH injection.

In conclusion, the inclusion of a CIDR insert in a TAI protocol may be successfully implemented when detection of estrus is a limiting factor for AI programs in dairy heifers.

The Ovsynch Protocol

One of the first ovulation synchronization protocols successfully developed for lactating dairy cows was Ovsynch (Pursley et al., 1995). Subsequent studies modified the original Ovsynch protocol in order to improve synchrony and fertility to the protocol. Such modifications include presynchronization with $PGF_{2\alpha}$ (Moreira et al., 2001), altering the timing of AI in relation to ovulation, and testing the various injection intervals of the original protocol (Fricke, 2004).

The Ovsynch protocol shown in Figure 17.1, consists of administering GnRH, followed 7 days later with an injection of $PGF_{2\alpha}$, 48 h later a second administration of GnRH, and TAI 16–24 h later (Pursley et al., 1995; Burke et al., 1996). The physiological principles for the

Figure 17.1. The Ovsynch protocol.

Ovsynch protocol have been reviewed by Pursley et al. (1995). The intention for the first injection of GnRH is to cause an ovulation of a large functional follicle, inducing a new follicular wave and increasing the likelihood for a large growing follicle at the time of $PGF_{2\alpha}$. Another function for this first GnRH injection is to increase the percentage of animals synchronized to a single injection of $PGF_{2\alpha}$, because a higher synchronization rate was achieved when GnRH was injected 6 or 7 days prior to $PGF_{2\alpha}$ administration (Thatcher et al., 1989). The 7-day period between the first GnRH injection and the $PGF_{2\alpha}$ injection was based on the fact that lactating dairy cows have a responsive CL by 7 days after estrus. The purpose of the second GnRH injection in the Ovsynch protocol is to ovulate the preovulatory follicle from the induced follicular wave after the first GnRH at a precise time, in order to increase synchrony of ovulation.

The Ovsynch Protocol in Dairy Heifers

When the Ovsynch protocol was developed for use in dairy cattle, it was evaluated either in lactating cows or heifers (Pursley et al., 1995). The authors found that 90% of cows, but only 54% of heifers responded to the first injection of GnRH by ovulating a dominant follicle. Due to the lower percentage of heifers ovulating to the first injection of GnRH, which resulted in only 75% of heifers being synchronized, this protocol did not appear to be as effective for synchronizing heifers as lactating dairy cows.

The Ovsynch protocol was compared to a detection of estrus program consisting of an injection of GnRH agonist followed by a $PGF_{2\alpha}$ injection 7 days later and AI at detected estrus (Schmitt et al., 1996). The Ovsynch protocol had greater P/TAI if the GnRH agonist injection was administered 48 h after $PGF_{2\alpha}$ injection (day 9) instead of 24 h (day 8) (45.5% vs. 25.8%, respectively). Nevertheless, P/TAI were always reduced in the TAI protocol.

These studies lead to the conclusion that dairy heifers respond poorly to the Ovsynch protocol; consequently, the application of this program has not been recommended for dairy heifers.

The Co-Synch Protocol

The Co-Synch protocol is based on the same physiological principles of the Ovsynch protocol, with the difference that TAI is performed at the same time of the second GnRH injection (Geary & Whittier, 1998) as shown in Figure 17.2. Thus, it requires one less handling of cows, resulting in a more labor-efficient synchronization program.

Figure 17.2. The Co-Synch protocol.

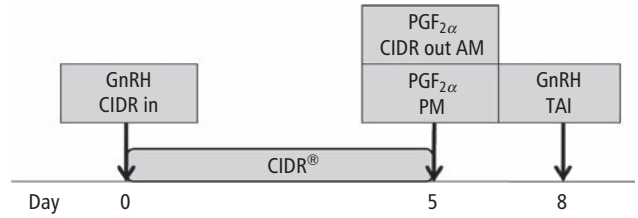

Figure 17.3. The 5-day Co-Synch + CIDR protocol.

The 5-Day Co-Synch + CIDR Protocol

This protocol was developed by Bridges et al. (2008), and consists of a modification of the Co-Synch program. The interval from the first GnRH treatment to the $PGF_{2\alpha}$ injection is reduced to 5 days, and the proestrus interval from $PGF_{2\alpha}$ to the second injection of GnRH/TAI is lengthened to 3 days. As a CIDR insert was applied between the first GnRH and the $PGF_{2\alpha}$ injections, the protocol is named the 5-day Co-Synch + CIDR, and is shown in Figure 17.3. This modification of the Co-Synch program was based on the hypothesis that reducing the interval from the initial GnRH treatment to $PGF_{2\alpha}$ and lengthening the interval until the second GnRH injection (proestrus period) would increase estradiol secretion by the preovulatory follicle and increase fertility. In beef cows, this approach resulted in higher P/TAI compared to a 7 days Co-Synch + CIDR with the second GnRH and TAI concurrently at 60 h (80.0% vs. 66.7%, respectively). Due to the shortened interval from the initial GnRH to $PGF_{2\alpha}$ in the 5-day Co-Synch + CIDR protocol, it is not known whether regression of an induced accessory CL occurs with one injection of $PGF_{2\alpha}$. Therefore, a second $PGF_{2\alpha}$ injection was applied approximately 12 h after the first $PGF_{2\alpha}$ injection, which results in additional animal handling and cost. However, in beef cows, the use of one injection of $PGF_{2\alpha}$ in the 5-day Co-Synch + CIDR protocol resulted in a 17% reduction in P/TAI compared with the use of two injections of $PGF_{2\alpha}$ (Kasimanickam et al., 2009).

In lactating dairy cows, one injection of $PGF_{2\alpha}$ in the 5-day Co-Synch 72-h protocol was not effective as two injections of $PGF_{2\alpha}$ to regress accessory CL, since CL regression was 58.7% and 95.8%, for one or two injections of $PGF_{2\alpha}$, respectively (Chebel et al., 2008). Two injections of $PGF_{2\alpha}$ appear to be necessary when this protocol is applied to beef or lactating dairy cows.

The 5-Day Co-Synch + CIDR Protocol in Dairy Heifers with One $PGF_{2\alpha}$ Injection

In an initial study in dairy heifers, the 5-day Co-Synch + CIDR protocol with two $PGF_{2\alpha}$ injections was used as a platform to determine if flumixin meglumine (FM) improved embryo survival and P/TAI (Rabaglino et al., 2010a). Total P/TAI was 59.5% at 45 days. The application of FM failed to improve P/TAI, but pregnancy results were acceptable for dairy heifers, showing that the 5-day Co-Synch + CIDR protocol could be successfully used in the reproductive management of dairy heifers.

The next step was to determine if the second dose of $PGF_{2\alpha}$ in this protocol was necessary in dairy heifers as it is in beef cows (Kasimanickam et al., 2009) or lactating cows (Chebel et al., 2008). To address this point, a series of studies were performed in two commercial dairies located in South Florida (SF) and North Central Florida (NCF) (Rabaglino et al., 2010b). The main objective of these experiments was to determine if the 5-day Co-Synch + CIDR protocol can be used in dairy heifers for a synchronized TAI with one injection of $PGF_{2\alpha}$ for first and second services. The protocol consisted of a first injection of GnRH (100 µg; Cystorelin®, Merial, Ltd., Iselin, NJ) and insertion of a CIDR containing 1.38 g of progesterone inserted at day 0; 5 days later (day 5), the CIDR was removed, and one or two injections (12 h apart) of $PGF_{2\alpha}$ (25 mg i.m.; Lutalyse®, Pfizer Animal Health, New York, NY) were administered; 3 days later, on day 8, a second injection of GnRH was administered concurrently with TAI as shown in Figure 17.4.

In experiment one, heifers were assigned randomly to receive one ($n = 295$) or two ($n = 298$) injections of $PGF_{2\alpha}$ in the 5-day Co-Synch + CIDR protocol. In one replicate ($n = 218$), CL regression was measured. No difference in P/TAI (46.1% and 48.6%) or CL regression (86.9% and 92.8%) was detected with one versus two injections of $PGF_{2\alpha}$, respectively. In experiment two, nonpregnant heifers ($n = 86$) were assigned to a resynchronized 5-day Co-Synch + CIDR with one $PGF_{2\alpha}$/TAI or insemination at detected estrus. There was no difference in P/TAI (52.2% and 55%) between groups. In experiment three, nonpregnant heifers ($n = 110$) were assigned randomly to receive a CIDR ($n = 54$) or no CIDR insert ($n = 56$) in the 5-day Co-Synch protocol for resynchronization of TAI. Pregnancy per TAI was lower without the CIDR device (39.3% vs. 51.8%). In a commercial field evaluation, 416 heifers were synchronized for the first and resynchronized TAI with the 5-day Co-Synch + CIDR protocol with one injection of $PGF_{2\alpha}$. Pregnancy per TAI on day 60 was 58.2% and 47.5% for first and second TAI, respectively; however, there was a sire effect to the second TAI.

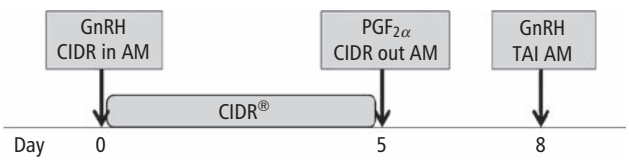

Figure 17.4. The 5-day Co-Synch + CIDR protocol with one $PGF_{2\alpha}$ injection.

The overall conclusion of these experiments was that the modified 5-day Co-Synch + CIDR protocol with one injection of $PGF_{2\alpha}$ at the time of the CIDR withdrawal and GnRH/TAI 72 h later is an efficient reproductive management program to achieve acceptable P/TAI in dairy heifers. Hence, this is an alternative program for managing reproduction in dairy heifers in herds that are not capable to perform daily observation of estrus efficiently.

Use of Sexed Semen in the 5-Day Co-Synch + CIDR Protocol in Dairy Heifers

The goal of sexed semen use in AI is to obtain an offspring of a preferred gender. In sexed semen, the fractions of X- and Y-bearing sperm have been modified from the natural mix through a sorting and selection process using a fluorescence-activated cell-sorting approach described by Johnson et al. (1987). Because of the sorting procedure which lowers sperm viability and the reduced sperm dose used, P/AI is lower with sexed semen than with the use of conventional semen (Seidel et al., 1999). Thus, it can be expected that P/AI would be 70%–80% of conventional semen (Seidel et al., 1999). To increase the probability of acceptable pregnancy results, Select Sires recommends restricting the use of sexed semen to first and second service of virgin heifers in standing estrus. The use of a TAI program in absence of observed estrus is discouraged (Thorban, 2008; DeJarnette et al., 2009). Nevertheless, the utility of TAI combined with the commercial availability of sexed semen could prove to be an effective reproductive management program of dairy heifers if acceptable P/TAI is obtained, especially in herds with inefficient estrous detection (De Vries et al., 2008).

It was hypothesized that the 5-day Co-Synch + CIDR protocol with one injection of $PGF_{2\alpha}$ would be an acceptable reproductive management program for TAI of dairy heifers with sexed semen. One experiment was conducted with the objective of comparing P/TAI using conventional or sexed semen for the first TAI. In commercial field verification, P/TAI was evaluated in dairy heifers after a reproductive management program with sexed

semen for the first TAI and sexed or conventional semen for the second TAI.

A total of 1000 Holstein heifers between 13 and 14 months of age were synchronized with the 5-day Co-Synch + CIDR protocol with one injection of $PGF_{2\alpha}$ (Rabaglino et al., unpublished results). In the experiment, 198 heifers were assigned randomly to be inseminated with conventional ($n = 98$) or sexed ($n = 100$) semen for the first TAI. Commercial straws with sexed or conventional semen were obtained from two sires. Pregnancy per TAI was 51.0% and 42.0% at 45 days for conventional and sexed semen, respectively. Pregnancy per TAI with sexed semen was 82.3% of conventional semen. In the field verification, a total of 802 heifers from two different locations (NCF and SF locations) were TAI to the first service with sexed semen. Overall P/TAI at first service with sexed semen was 39.3% at 32 days and 35.9% at 60 days after TAI. For the resynchronized TAI, nonpregnant heifers at 32 days after the first TAI were resynchronized with the 5-day Co-Synch + CIDR and were TAI with sexed semen (SF location, $n = 114$) or with conventional semen (NCF location, $n = 373$). P/TAI was 40.4% with sexed semen at 45 days and 59.2% with conventional semen at 60 days. As expected, P/TAI was lower with sexed semen compared to conventional semen. Nevertheless, the application of the 5-day Co-Synch + CIDR protocol with one injection of $PGF_{2\alpha}$ as a reproductive management program for TAI of dairy heifers achieved an acceptable P/TAI with sexed semen. We conclude that sexed semen can be used with TAI to effectively manage reproduction in dairy heifers by removing the challenges of detection of estrus and increase the number of females born.

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18

Managing Mastitis and Producing Quality Milk

Pamela L. Ruegg

Abstract

Mastitis is a major cause of morbidity and mortality of adult dairy cows lowering profitability for the dairy farmers. On most farms, detection, diagnosis, and administration of treatments for clinical mastitis are the responsibility of farm personnel, and veterinarians are often consulted only when a case becomes life-threatening. Increased involvement in the design and implementation of mastitis control programs is a potential growth area for many production medicine practices. The successful implementation of a milk quality program as part of the herd health program will improve economic performance for the dairy farm.

Introduction

Mastitis remains one of the most significant causes of morbidity and mortality of adult dairy cows and results in reduced profitability for the dairy industry (USDA, 2008). Consolidation of dairy herds has resulted in the continued shift of dairy cows from smaller to larger herds. In 2010, dairy herds containing more than 500 cows comprised about 5% of all herds, yet produced 61% of total U.S. milk output (USDA, 2011). Larger dairy farms manage cows in groups, have specialized labor forces, and often have apparently free access to technical services provided by agribusinesses. These demographic shifts have influenced the role of veterinarians in developing and implementing mastitis control programs. On most farms, detection, diagnosis, and administration of treatments for clinical mastitis are the responsibility of farm personnel and veterinarians are often consulted only when a case becomes life-threatening. Several studies have indicated that many dairy veterinarians are only marginally involved in mastitis control programs. Only 24% of dairy farmers ($n = 180$) enrolled in a milk quality program in Wisconsin indicated that they used their herd veterinarian to plan milk quality programs (Rodrigues et al., 2005). In a companion survey, most dairy veterinarians ($n = 42$) interested in participating in a mastitis control program indicated that they spent <10% of their professional time actively working to improve milk quality (Rodrigues & Ruegg, 2004). Increased involvement in the design and implementation of mastitis control programs is a potential growth area for many production medicine practices. The involvement of the production medicine veterinarian in mastitis control is especially important because treatment and control of mastitis accounts for most doses of antimicrobials given to adult dairy cows (Pol & Ruegg, 2007).

There are ample economic and societal reasons for veterinarians to increase their involvement in mastitis control programs. The occurrence of mastitis reduces milk production, increases the amount of milk discarded, and increases premature culling and production costs (Fetrow, 2000). Additionally, both clinical and subclinical mastitis have been demonstrated to reduce reproductive efficiency (Barker et al., 1998; Schrick et al., 2001; Santos et al., 2004). The objective of dairy production medicine is to prevent animal disease, improve animal well-being, reduce treatments, and help ensure the profitability of the dairy business. The successful

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implementation of a milk quality plan as part of the production medicine program will help to meet those objectives and can result in improved economic performance for the dairy farm.

It is well-known that mastitis can be controlled by prevention of new infections and elimination of existing infections. The 5-point plan (consisting of postmilking teat disinfection, comprehensive use of intramammary antimicrobial therapy at dry-off, appropriate treatment of clinical cases, culling of chronically infected cows, and regular milking machine maintenance) has been demonstrated to successfully control contagious mastitis pathogens and has been expanded to a 10-point plan that includes management procedures that reduce exposure to environmental pathogens (NMC, 2009). The prevalence of contagious pathogens has decreased as herds have modernized and adopted these practices (Makovec & Ruegg, 2003b). Milk quality programs now tend to be focused on prevention of mastitis caused by environmental pathogens and other issues that influence consumer perceptions of milk quality.

Historically, milk quality was defined by dairy processors based solely on characteristics of the raw milk that they purchased. In most regions, quality standards consisted of measurements of somatic cell count (SCC), total bacterial count, and detection of antimicrobial residues (Anonymous, 2009). Most modern farms successfully meet official regulatory standards, but the concept of quality milk has been expanded. Modern consumers expect milk to be safe and inexpensive and produced using practices that meet their evolving expectations for animal care and environmental sustainability. These expectations are in agreement with goals of most production medicine programs. Veterinarians who offer dairy production medicine programs should have a solid understanding of milk quality concepts, work in a practice structure that allows them to charge for the development of individual farm milk quality plans, and actively consult with other dairy advisors to successfully implement, assess, and revise these plans.

Milk Quality Terminology and Background

Traditional Definition of Milk Quality

For many years, quality standards were fairly consistent and enforced by state regulatory officials. In the United States, national regulatory standards require farmers to maintain bulk milk SCC < 750,000 cells/mL, but most processors enforce more stringent standards and often pay premiums for milk produced with SCC <400,000 cells/mL. Since 1995, the average SCC in the United States has decreased about 3% annually (Norman et al., 2009). In 2008, average SCC of all Dairy Herd Improvement

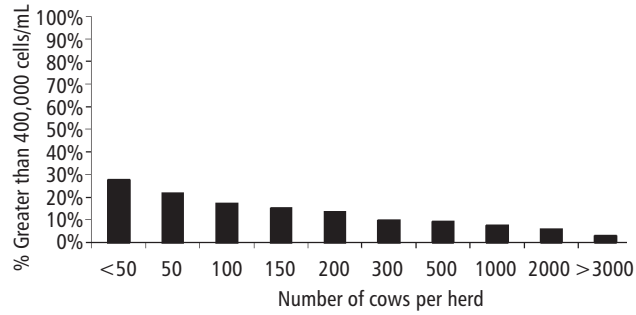


Figure 18.1. Percent of Herd Test Days >400,000 cells/mL in 2008 by Herd Size Category for U.S. Herds that use DHIA Monthly Somatic Cell Count Testing (from Norman et al., 2009).

Association (DHIA) herds was 262,000 cells/mL, but 22% of all herd test days exceeded 400,000 cells/mL. Part of the improvement in SCC is related to herd size because a disproportionate number of smaller herds contribute test days with greater SCC (Fig. 18.1, from Norman et al., 2009). Standard plate count (SPC) is the official reference method used for estimating bacterial populations of raw milk and is specified in the Grade A Pasteurized Milk Ordinance (PMO) (Anonymous, 2009). The PMO requires Grade A farms to maintain SPC less than 100,000 cfu/mL. For the few remaining Grade B farms, regulations require SPC to be maintained less than 300,000 cfu/mL. Few dairy producers consistently exceed these regulatory limits. Of 804,575 monthly SPC values examined for Wisconsin Grade A farms between 1994 and 1998, 90% were <34,000 cfu/mL (Ruegg & Tabone, 2000). Many milk purchasers have standards for SCC and SPC that are more rigorous than the official regulations. A reasonable goal for SPC is ≤5000 cfu/mL and a count of >10,000 cfu/mL is usually indicative of a problem (Reinemann et al., 1999; Jayarao et al., 2004).

Clinical Mastitis

Mastitis occurs in both clinical and subclinical forms. Signs of clinical mastitis are highly variable and can range from detection of a small amount of garget at the beginning of milking to swollen, red mammary quarters and mortally ill cows. Milking technique can influence the perception of clinical mastitis. On many farms, subtle signs of mastitis are overlooked or disregarded. If milking routines do not include examination of foremilk, only severe cases of clinical mastitis may be detected. In this instance, highly variable bulk tank SCC values or the presence of garget on milk filters may be the only indication that abnormal milk is going into the bulk tank.

Subclinical Mastitis

Subclinical disease is defined as abnormalities of function that are detectable only by diagnostic or laboratory

tests. Subclinical mastitis is the most prevalent mastitis problem on most farms. Detection of subclinical mastitis is based on the use of indirect tests such as enumeration of somatic cells or bacteriological analysis of milk samples. Subclinical mastitis is often undetected and has the greatest economic consequence because of long-term reductions of milk yield. Production losses due to subclinical mastitis have been estimated to cost the U.S. dairy industry $1 billion dollars annually (Ott, 1999).

Contagious Pathogens

Organisms that cause mastitis are often classified as "contagious" or "environmental" based on their primary reservoir and mode of transmission. The udder of cows with subclinical infections serves as the primary reservoir for contagious pathogens and transmission occurs when teats of uninfected cows are exposed to organisms present in milk that originated from infected udders. Droplets of infected milk left on fomites such as milking equipment, towels used to dry teats of several cows, hands of milking technicians, or infected milk left on bedding surfaces are common mechanisms for the spread of contagious mastitis. In the United States, the most common contagious mastitis pathogens are *Staphylococcus aureus* and *Mycoplasma bovis*, but a few herds may still experience problems with *Streptococcus agalactiae*. Other host-adapted organisms that cause persistent subclinical mastitis and shed a large number of colonies in milk may also be transmitted in a contagious fashion (e.g., some environmental *Streptococci* spp. and organisms such as *Klebsiella* spp.). In most instances, quarters that are subclinically infected with contagious pathogens will have SCC that range from 200,000 to more than 10,000,000 cells/mL. Successful control programs for contagious mastitis are focused on reducing exposure of teats to pathogens found in milk that originated from infected cows.

Environmental Pathogens

The term "environmental pathogen" refers to mastitis caused by opportunistic bacteria that reside in the environment of the cows. Common environmental mastitis pathogens include gram-negative bacteria (such as *Escherichia coli* and *Klebsiella* spp.) and gram-positive bacteria (such as *Streptococcus uberis* and *Streptococcus dysgalactia*). Moisture, mud, and manure in cow housing areas are common reservoirs for these pathogens. Environmental pathogens tend to be less adapted to survival in the udder and often stimulate an acute immune response when they infect the udder. For some environmental pathogens (such as *E. coli*), the immune response usually eliminates these pathogens, thus resulting in a high rate of spontaneous cure. Consequently, the natural duration of infection may be relatively short, and the only sign of infection may be a brief period of abnormal milk with or without changes in appearance of the udder. Other environmental pathogens (such as *Streptococci* spp.) may present as mild clinical cases that erroneously appear to resolve when they return to a subclinical state. Initial exposure to environmental pathogens often occurs in areas other than the milking facility (such as housing areas, pastures, or walkways). Successful control of environmental pathogens is based on reducing exposure of teats to pathogens present in the environment.

Antimicrobial Residues

Mastitis was the first disease of dairy cattle to be treated with antimicrobials and remains the most common disease of dairy cows. As a consequence, treatment of mastitis is the most common reason for administration of antimicrobials to adult dairy cattle (Mitchell et al., 1998; Pol & Ruegg, 2007). The use of intramammary antimicrobials and mistakes regarding withholding periods of milk are the most frequently cited reasons for violations caused by residues (McEwen et al., 1991). The FDA has accepted appendix N of the Grade A PMO as the official reference regarding testing for drug residues in milk. Appendix N requires every tanker of milk to be screened for β-lactam residues prior to unloading. Individual bulk milk samples from every farm are tested once monthly 4 times in every 6-month period. Additional random testing for other drug classes is also performed and individual state regulatory agencies or individual milk processors may test more frequently. Results of official drug testing are compiled annually in the National Milk Drug Residue Database (www.fda.gov/Food/FoodSafety/Product-SpecificInformation/MilkSafety/MiscellaneousMilkSafetyReferences/default.htm). Regulatory and quality assurance programs directed at reducing antimicrobial residues have been successful. In 2010, only 0.025% of bulk milk tank samples tested positive for antimicrobial residues. In the future, multiplex screening methods will likely be used to increase the number and classes of antimicrobials that are routinely screened for in milk.

Trends in the Epidemiology of Clinical Mastitis

Most cases of clinical mastitis are mild to moderate in severity and are treated by farm personnel without consulting the herd veterinarian. Few production medicine veterinarians are aware of the incidence of clinical mastitis on dairy farms nor are they familiar with the outcomes of most mastitis treatments. Rates of clinical

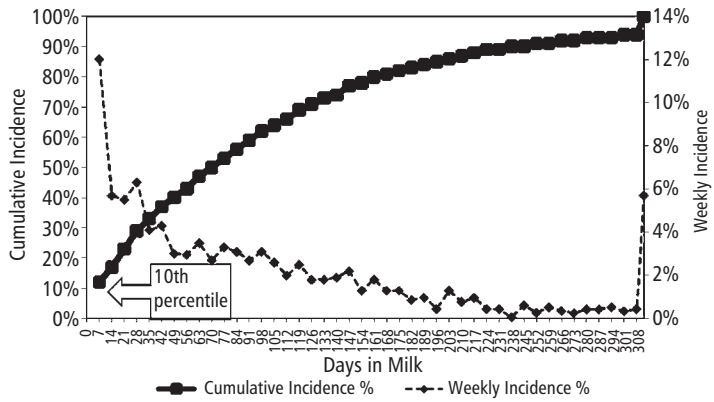


Figure 18.2. Occurrence of first case of mastitis by days in milk for 1150 cases of clinical mastitis occurring in cows on two Wisconsin dairy farms in 2005.

Table 18.1. Typical distribution of pathogens causing clinical mastitis in modern U.S. dairy herds

	Nash et al., 2002	Hoe & Ruegg, 2005	Pantoja et al., 2009b	Hohmann, 2008	Lago et al., 2005
Pathogen	686 cases in 7 herds	217 cases in 4 herds	68 cases in 1 herd	1108 cases in 2 herds	421 quarter cases in 8 herds
Streptococcus agalactiae[1] or *Staphylococcus aureus*	6%	0%	1%	0%	6%
Coag. Neg. Staph	19%	14%	12%	26%	10%
Environmental streptococci	32%	24%	26%	28%	16%
Coliform	17%	25%	29%	13%	25%
Other	11%	8%	9%	6%	10%
No growth	19%	29%	24%	25%	32%

[1] *S. agalactiae* was found only in Nash et al., 2002.

mastitis vary dramatically among studies because of differences in detection intensity and case definition. A review of disease studies over 26 years reported an average rate of clinical mastitis of 14.2%, but the range among studies was 1.7%–54.6%, and different studies used different definitions of clinical mastitis (Kelton et al., 1998). National surveys in both the United States (USDA, 2008) and Canada (Olde Riekerink et al., 2008) have reported about 16% of cows experience clinical mastitis each year; however, great variability among farms was noted. Veterinarians should be aware that bulk tank SCC values are not always well correlated with the clinical case rate. A study of U.K. dairy herds that maintained bulk tank SCC values of <100,000 cells/mL reported a quarter incidence rate of clinical mastitis of 36.7%; the average proportion of the herd affected was 23.1% (Peeler et al., 2000). In a study conducted in the United States, herds with SCC < 150,000 cells/mL reported 4.23 cases of clinical mastitis per 100 cows per month (Erskine et al., 1988).

Clinical mastitis can occur throughout the lactation cycle, but a disproportionate proportion of severe mastitis cases occur in early lactation during the periparturient period of immune suppression. When monitoring incidence, a good rule of thumb for the occurrence of the first case of mastitis is to expect about 10%, 30%, and 60% of first cases of clinical mastitis to occur in the first week, first month, and the rest of lactation, respectively, as shown in Figure 18.2. Deviation from this rule of thumb indicates that risk factors associated with exposure should be investigated.

The emergence of environmental pathogens as common mastitis organisms (Table 18.1) has likely influenced the perception of treatment outcomes. The increased prevalence of pathogens with relatively large rates of spontaneous regression of clinical symptoms reduces the ability of veterinarians to perceive "true cures" (complete elimination of intramammary infection including elimination of the subclinical state of infections).

Parity is an important risk factor for clinical mastitis and most data demonstrate that older cows are at greater risk. The effect of parity can impact both the risk of

developing contagious mastitis (because the period of exposure to infected milk is longer as cows age) and environmental mastitis (because older cows may have weaker teat sphincters and less ability to resist infection). Parity is also an important risk factor because a history of clinical mastitis is a strong predictor of future risk. In a study that followed 218 cows, multiparous cows that experienced a clinical case of mastitis in the previous lactation were 4.2 times more likely to have a case in the first 120 days of the next lactation as compared to cows that had completed the previous lactation without a case (Pantoja et al., 2009a). This risk should be accounted for when making treatment decisions and when making medical histories of cattle.

Trends in the Epidemiology of Subclinical Mastitis

Mastitis occurs when bacteria successfully colonize the teat end, establish sufficient numbers to overwhelm teat and systemic immune defenses, and establish an infection within the udder. Many cases of mastitis present as a syndrome with the infected quarters alternating between a clinical state (abnormal milk) and a subclinical state (visually normal milk with an excessive number of immune cells present). By definition, subclinical mastitis implies that the milk contains large numbers of inflammatory cells, so subclinical mastitis is usually diagnosed based on SCC values that exceed a predefined threshold (such as 200,000 cells/mL). In healthy mammary glands, epithelial cells, macrophages, and lymphocytes are the predominant cell type while neutrophils are predominant in the infected gland (Leitner et al., 2000). When bacteria successfully invade the udder, immune mediators released by resident cells signal the immune system to attract neutrophils to the infected quarter to destroy the pathogens. To date, bacterial infections are the only significant agents that have been associated with the influx of somatic cells to the udder (Hortet & Seegers, 1998). The SCC of a quarter that is not infected is almost always <200,000 cells/mL and the majority of uninfected quarters will contain <100,000 cells/mL. The presence of >200,000 cells/mL in quarter milk is a strong indicator of mastitis even when milk samples obtained from that quarter are bacteriologically negative.

Developing a Milk Quality Plan

Mastitis is a bacterial disease that occurs in individual animals, but mastitis control programs must be implemented at the herd level. Successful control of mastitis is dependent on effective detection, accurate diagnosis, evaluation of appropriate treatment options, and implementation of preventive practices that address herd-specific risk factors associated with exposure to mastitis pathogens. As part of the production medicine program, veterinarians should regularly review herd records for SCC and clinical mastitis and evaluate key performance indicators (KPIs)relative to herd goals. The program should be structured to allow for the evaluation of cow factors, environmental factors, and milking machine factors that can contribute to exposure to mastitis pathogens. Production medicine veterinarians should be advocates for enhancing the well-being of dairy cows. They should assume key leadership roles to ensure that each farm has an appropriate milk quality plan that is frequently reviewed and updated. Key areas of veterinary involvement include

- Measuring and monitoring mastitis and milk quality
- Ensuring that appropriate diagnostic methods are used
- Ensuring effective and judicious use of therapeutics used for treatment
- Implementing effective practices that reduce exposure to mastitis pathogens
- Working with other professionals to implement best management practices

Measuring and Monitoring Mastitis and Milk Quality

An effective surveillance system for mastitis includes the following elements: (1) clear case definitions and effective mechanisms to detect both clinical and subclinical mastitis; (2) recording systems that allow for timely evaluation of risk factors; and (3) feedback mechanisms that allow management personnel and veterinarians to manage milk quality.

Defining and Detecting Clinical Mastitis

While clinical mastitis is technically defined as the production of abnormal milk with or without secondary symptoms, the working definition of clinical mastitis varies greatly among farm personnel. On large farms, detection of mastitis is usually dependent on the observational skills of the milking technicians, and on some farms, communication about cases may be impeded by language barriers. Veterinarians should actively communicate with milking technicians and farm management personnel to be sure that the definition of clinical mastitis and intensity of detection are consistent with farm goals. Case definitions should be simple and easily understood by all farm personnel. Most cases of clinical mastitis are mild to moderate in severity, and

Table 18.2. Expected distribution of severity scores for clinical mastitis from selected studies

		Study 1[1]	Study 2[2]	Study 3[3]	Coliform cases only[4]
Severity score	Clinical symptom	$n = 686$	$n = 169$	$n = 212$	$n = 144$
1	Abnormal milk only	75%	57%	52%	48%
2	Abnormal milk and abnormal udder	20%	20%	41%	31%
3	Abnormal milk, abnormal udder, and sick cow	5%	23%	7%	22%

[1] Nash et al., 2002.
[2] Oliveira, 2009.
[3] Rodrigues et al., 2009.
[4] Wenz et al., 2001 (different but equivalent scoring system used).

are not examined by veterinarians. The use of a severity scoring system for clinical cases (Wenz et al., 2001) can be used as an important monitor of detection intensity, and practitioners should encourage the recording of severity scores for each case in the permanent treatment records of each cow. The use of a 3-point scale based on clinical symptoms is practical, intuitive, simply recorded, and can be an important way to assess detection intensity and is shown in Table 18.2. When using a 3-point scale, if the proportion of severe cases should exceed about 20% of all cases, it is a signal that detection intensity and case definition should be investigated.

Monitoring Clinical Mastitis

Animal health recording systems should consist of both temporary cow-side records (often used for day-to-day decision making) and permanent records (such as cow cards or computerized records) that are used to summarize trends over time (Rhoda, 2007a,b). While temporary records (such as treatment notes on whiteboards and calendars in milking facilities) are common, the use of permanent record systems for recording mastitis is more limited. A representative survey of Wisconsin dairy herds ($n = 587$ herds) indicated that making a notation on a calendar was the most common recording system for clinical mastitis, and the use of computerized mastitis records was almost entirely restricted to herds with >200 cows (Hoe & Ruegg, 2006). The ideal system for recording clinical mastitis will allow the practitioner to evaluate important cow factors that define the probability of treatment success and to assess epidemiological trends (Wenz, 2004). To begin involvement in mastitis control programs, production medicine veterinarians should ensure that the following questions can be answered (adapted from Wenz, 2004; Table 18.3):

- What is the incidence (rate of new cases) of clinical mastitis?
- What proportion of cases are severe (severity score 3)?
- What are the most common bacteria that are causing clinical mastitis?
- What are the current treatment protocols?
- How many days is milk discarded as a result of treatment?
- How many cases: (1) require changes to the original treatment protocol and (2) experience recurrence of the case within the same lactation?
- What percentage of lactating cows are being milked on less than 4 quarters?
- What percentage of cows that experience clinical mastitis are culled in the same lactation or die?

Practitioners who work with small herds will generally need to review data found in paper-based treatment diaries and will need to include data collected over longer time periods (2- to 3-month periods) in order to discern trends. For larger herds, computerized dairy management record systems (such as Dairy Comp 305, PCDart, DHIPlus, and others) should be configured to allow practitioners to rapidly review appropriate data (Rhoda, 2007a,b). For ease of interpretation, data entry should be structured to avoid redundancy, and only one mastitis event should be entered for each discrete case (defined at the cow level) (Wenz, 2004). Researchers generally define separate cases of clinical mastitis based on an interval of 14–21 days between occurrences, but this time period is not based on sound research and may be adapted to meet the needs of the farm. KPIs that are defined at the cow level (occurrence of mastitis in one or more quarters of a cow) rather than the individual quarter are easier to record and may better reflect the important economic consequences of mastitis (Table 18.3). These KPIs are derived from populations of herds

Table 18.3. Calculation of suggested key performance indicators for clinical mastitis. For ease of interpretation, a case is defined as the occurrence of mastitis in one or more quarters of a cow (cow-level definition)

Indicator	Calculation[a]	Suggested goal
Incidence rate	Sum of first cases occurring in the appropriate time period[a] divided by average number of lactating cows in the same time period[b]	<25 new cases per 100 cows per year (about 2–3 cases per 100 cows per month)
Proportion of cases scored 3 (severe)	Number of severity score 3 cases occurring divided by the total number of cases occurring	5–20% of total cases
Proportion of cases that die	Number of cows experiencing mastitis cases that resulted in death divided by the total number of cows experiencing mastitis	2%[c]
Distribution of culture results for clinical mastitis pathogens	Results of culture data from all or most cases of clinical mastitis	0% Mycoplasma 0% *Streptococcus agalactiae* <2% *Staphylococcus aureus* 25% no growth 40% gram-negative 15% *Streptococcus* spp. 15% CNS and other gram-positive <3% contaminated
Proportion of cases requiring treatment changes	Number of cases that have the initial treatment protocol changed or supplemented because of nonresponse divided by the total number of detected cases[e]	<20%[d]
Proportion of cases that are recurrent (second or greater treatment)	Number of cows with second or greater case of mastitis occurring >14 days posttreatment divided by the total number of cases of mastitis	<30%
Proportion of cows with >1 quarter affected	Number of cases with 2+ quarters affected divided by the total number of cases	<20%
Number of days milk discarded (per case)	Sum of the number of discard days for the time period divided by the total number of cases	4–6 days (unless many cows are receiving extended therapy because of a high prevalence of *S. aureus*)
Percent of herd milking with <4 quarters	Number of cows milking with <4 quarters[f] divided by the number of lactating cows	<5%

[a]Numerators and denominators in all indices should include the statement "in the appropriate time period." The appropriate time period will vary depending on herd size. Smaller herds may need to calculate indices on a quarterly basis.
[b]A more correct denominator would exclude cows that had previously experienced a clinical case within that lactation; the inclusion of cows with previous cases produces a more conservative estimate.
[c]Estimated based on 15% of clinical mastitis cases grade 3 (severe) and 15% of those result in death (Erskine et al., 2002).
[d]Lago et al., 2008.
[e]Cases that are detected but do not receive initial antimicrobial treatments should be included in this calculation.
[f]Herds that use quarter milkers to discard milk from selected quarters should include those cows in the numerator.

and may need to be adjusted for individual herd circumstances.

Monitoring Subclinical Mastitis

It is not possible to control any subclinical disease without a clear understanding of prevalence and a mechanism to monitor incidence. Prevalence of mastitis is a function of incidence (development of new subclinical cases) and duration. For some herds, prevalence of subclinical mastitis may exceed goals even when relatively few new infections are occurring because of long-duration infections caused by contagious pathogens. Alternatively, goals may be exceeded because of environmental mastitis problems that are characterized by high incidence of new infections of relatively short duration. Dairy herds that do not

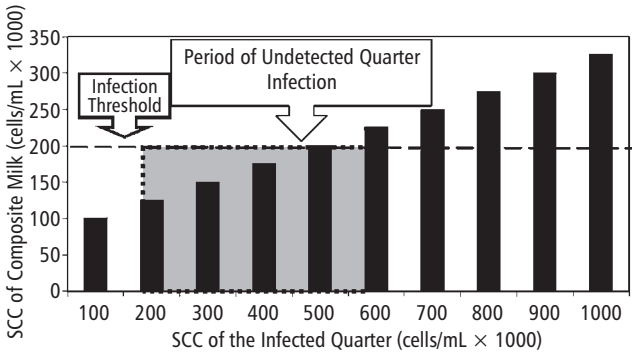


Figure 18.3. Example of estimated composite milk somatic cell count (from all four quarters) when a single quarter is infected and the baseline SCC in uninfected quarters is 100,000 cells/mL.

routinely test for the presence of somatic cells in milk cannot accurately manage subclinical mastitis. Thus, the first step in monitoring subclinical mastitis is to ensure that SCC values are routinely obtained from all cows on a regular basis. Generally, all cows with SCC values >200,000 cells/mL (linear somatic cell score of approximately 4.0) are considered to have subclinical mastitis. The use of this threshold is based on normal physiologic response to infection and epidemiologic characteristics that minimize diagnostic error (Dohoo & Leslie, 1991). In most herds, the most frequently available SCC values (e.g., monthly DHIA tests) are performed on milk that has been commingled from all 4 quarters. Monitoring these composite SCC values is highly useful for evaluation of herd trends, but it is important to remember that these values underrepresent the actual incidence of subclinical mastitis at the quarter level. Consider the hypothetical situation when a cow is producing 20 kg of milk per milking evenly distributed between 4 quarters (5 kg per quarter) and a single quarter is infected with subclinical mastitis. If the SCC of the milk from the three uninfected quarters is 100,000 cells/mL, the composite SCC value will not reach a threshold of 200,000 cells/mL until the SCC from the infected quarter exceeds 600,000 cells/mL (Fig. 18.3). This long period of unrecognized infection can result in the development of chronic mastitis infections that may be accompanied by recurrent periods of mild to moderate episodes of clinical mastitis in cows that are apparently healthy. Practitioners can assess SCC at the quarter level using a variety of cow-side tests such as the California Mastitis Test (CMT), the Direct Cell Counter (DCC—available from Delaval), or the PortaSCC (available from PortaCheck). Assessments of subclinical mastitis should begin with the following questions (Table 18.4):

- What is the prevalence of subclinical mastitis (defined based on SCC)?
- What is the incidence of subclinical mastitis (defined based on SCC)?
- What are the most common bacteria recovered from cows with SCC values >200,000 cells/mL?
- What proportion of subclinical cases are chronic (persist more than 2 months)?
- What is the prevalence of subclinical mastitis by days in milk and parity?
- What proportion of cows has subclinical mastitis at the first test and the last test?

Table 18.4. Calculation of suggested key performance indicators for subclinical mastitis

Indicator	Calculation	Suggested goal
Prevalence	Number of cows with SCC > linear score 4[a] divided by the number of cows with somatic cell counts (SCCs)	<15% of the herd
Incidence	Number of cows with SCC > linear score 4[a] for the first time in the time period of interest[b] divided by the number of cows with SCC below the threshold in the previous time period	<5% if incidence is determined based on the first SCC above threshold in the lactation; up to 8% if calculated based on month-to-month changes in SCC[b]
Prevalence at 1st DHIA test	Number of cows with SCC > linear score 4[a] at the 1st DHIA test divided by the number of cows with first test DHIA SCCs	<5% of 1st lactation <10% of lactation 2+
Prevalence at last DHIA test before dry-off	Number of cows with SCC ≥linear score 4[a] at the last DHIA test before dry-off of the lactation divided by the number of cows with last test DHIA SCCs	<30% of cows with last test days before dry-off

[a]For the purpose of herd monitoring, linear somatic cell score of 4 is used interchangeably with SCC of >200,000 cells/mL.
[b]The appropriate time period will vary depending the intended use of this index. Many DHIA centers and computer management programs will calculate this index based on changes between 2 months. Others may calculate it based on the SCC values available in the current lactation.

Data to answer these questions can often be found in summarized reports available from DHIA testing centers or the data can be downloaded and manipulated in customized spreadsheets or dairy management programs. The prevalence of subclinical mastitis is dependent upon just two factors: the new infection rate (percentage of cows developing new subclinical infections) and the duration of each subclinical infection. Common KPI for subclinical mastitis are: *85% cows with SCCs ≤200,000 (prevalence)* and *<5% of cows developing new subclinical mastitis infections per month (incidence)* (Table 18.4).

SCCs should be reviewed monthly at both the herd level and at the cow level. At herd level, evaluation of monthly SCC patterns can be highly diagnostic for troubleshooting subclinical mastitis problems. For example, herds that exceed targets for prevalence of subclinical mastitis (as defined by SCC > 200,000 cells/mL) at first test are often herds that are experiencing problems with environmental mastitis pathogens. In these cases, housing conditions, udder hygiene, and management of dry and periparturient cows should be investigated. In contrast, when contagious mastitis is a problem, prevalence of subclinical mastitis (defined using SCC values greater than 200,000 cells/mL) usually increases as lactation progresses and as cows age because of more opportunities for exposure to infected milk. When contagious mastitis is suspected, transmission of mastitis pathogens during milking should be investigated with special emphasis on detecting inadequate teat dipping or the presence of fomites (such as towels used to clean or dry more than one cow). A large proportion of cows with apparently chronically increased SCC (more than two consecutive monthly tests exceeding the threshold) indicates that cows are infected with host-adapted pathogens that are usually transmitted in a contagious manner. At the cow level, practitioners often find it helpful to review a list of individual cows sorted by SCC to identify cows that may require individual interventions. The use of a rapid cow-side quarter-level SCC test can help farmers make important management decisions such as whether or not to segregate, treat, culture, withhold high SCC quarters, or cull the cow.

Measuring and Monitoring Bacteriological Quality of Bulk Milk

Few veterinarians are actively involved in monitoring bacteriological quality of bulk milk but processors are increasingly paying premiums based on bacteriological qualities. Many processors measure bacteriological quality of milk on every tanker load of milk and provide online access to daily milk quality reports. Veterinarians can gain access to these reports by gaining permission from their client. Bacteriological contamination of raw milk can occur from two basic sources: (1) organisms can contaminate milk from environmental sources (especially contamination during the milking process) or (2) via mastitis organisms from within the udder (Reinemann et al., 1999). Raw milk from healthy udders normally contains <1000 total bacteria/mL and, therefore, do not significantly contribute to total numbers of microorganisms in bulk milk, or to a potential increase in bacterial numbers during refrigerated storage (Murphy & Boor, 2000). It is unusual for mastitis to contribute to increased total bacteriological counts in raw milk, but occasionally cows with mastitis can shed large numbers of microorganisms. At the cow level, the influence of mastitis on the total bacteria count in milk mostly depends on pathogen type and stage of infection. Some infected cows can shed more than 10,000,000 bacteria/mL (Bramley & McKinnon, 1990). At herd level, the effect of bacterial shedding on bulk tank bacterial count depends on the size of the herd, number of mastitic cows, and ratio of mastitic to nonmastitic milk (Hayes et al., 2001). Investigations of bacteriological quality of raw milk begin with the following questions:

- How many tests of bacteriological quality have been performed and do the counts demonstrate a trend or a "spike?"
- What is the average, minimum, and maximum SPC?
- What other diagnostic tests of milk quality have been performed and how do they compare?
- If available, what are the values for: (1) laboratory pasteurized count (LPC); (2) preliminary incubated count (PIC); and (3) coliform count (CC)?

Almost all U.S. farms easily achieve the regulatory goals for bacteriological quality of bulk milk (SPC < 100,000 cfu/mL), and most processors enforce much more rigorous standards that include more measurements than just SPC. The SPC is an overall measure of milk quality, but a single SPC value is not very useful diagnostically. Consistently increased values for SPC are an indication of a milk quality problem, and the best diagnostic strategy is to perform strategic sampling of milk at various points throughout the milking process. Comparison among the values of diagnostic counts (SPC, LPC, coliform count, and SCC) can give valuable clues as to the likely source of the problem (Fig. 18.4) (Reinemann et al., 1999). The LPC is basically an SPC performed on milk that has been heated to 145°F (62.8°C) and held for 30 min (low temperature-long time pasteurization). The objective of performing the LPC is to identify organisms that survive pasteurization (thermoduric bacteria). Typical mastitis-causing organisms do not survive pasteurization. Thermoduric

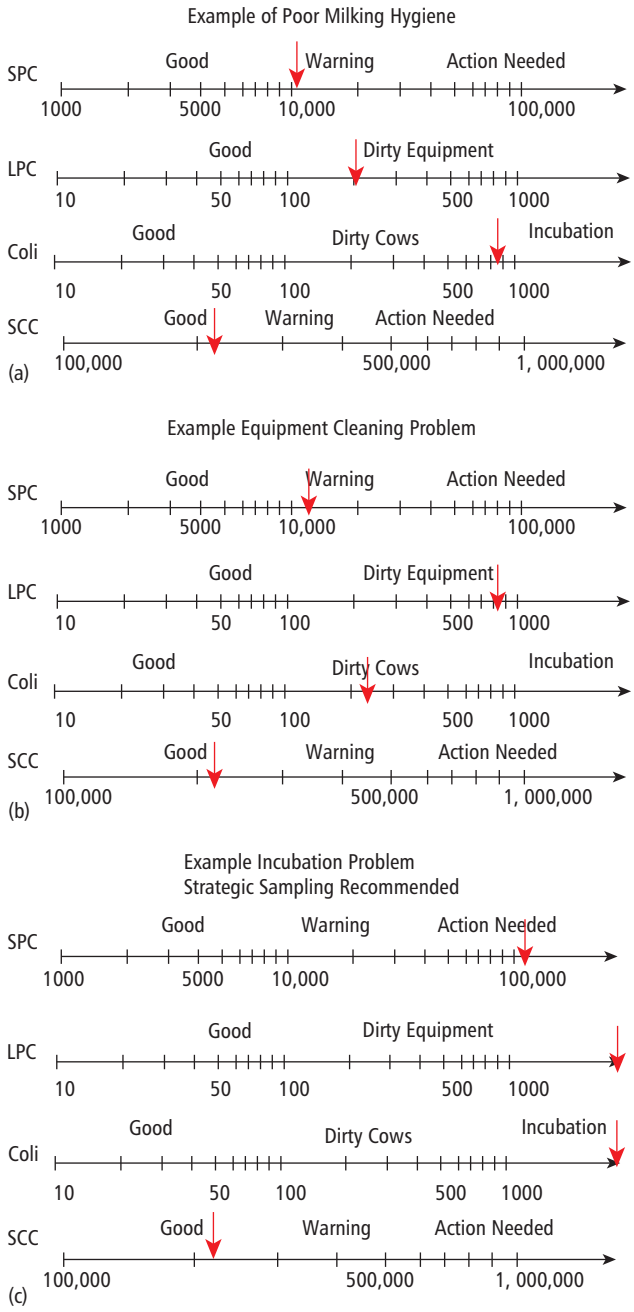


Figure 18.4. Comparison of diagnostic bacterial counts for investigation of bacterial count problems (from Reinemann et al., 1999). SPC = standard plate count; LPC = laboratory pasteurized count; coli = coliform count; and SCC = somatic cell count.

bacteria may include *Micrococcus*, *Microbacterium*, *Lactobacillus*, *Bacillus*, *Clostridium*, and occasional *Streptococci*. Increased LPC are often associated with the development of biofilms on unclean equipment. The LPC should be less than 100–200 cfu/mL, and an LPC below 10 cfu/mL indicates excellent equipment hygiene (Reinemann et al., 1999).

The most common misapplication of the method to solve the source of the problem following Figure 18.4, is the formulation of a diagnosis based on only one of these numbers without considering the others. A relative comparison of these numbers using a three-part decision tree is necessary to formulate a diagnosis. For example

1. *COLI is between 100 and 1000*
   - AND LPC is less than COLI
   - AND SPC is moderately elevated (5000–20,000)

   Interpretation: Implies milking wet and/or dirty cows.
2. *LPC is between 100 and 1000*
   - AND COLI less than LPC
   - AND SPC is moderately elevated (5000–20,000)

   Interpretation: Implies a persistent milking machine cleaning problem.
3. *COLI is greater than 1000 (or TNTC)*
   - AND LPC is greater than 100 but less than COLI (or TNTC)
   - AND SPC is extremely elevated (greater than 50,000–100,000 or TNTC)

   Interpretation: Implies incubation in the milk handling system. Multiple sanitation problems could be contributing to these elevated counts, and further investigation is recommended (strategic sampling).

Goals for high-performing herds are set by processors and are not uniform across the industry, but SPC of <5000 cfu/mL and LPC of <200 cfu/mL are reasonable goals for high-performing herd (Table 18.5; Jayarao et al., 2004; Pantoja et al., 2009c).

Ensuring that Appropriate Diagnostic Methods Are Used

Mastitis is a bacterial disease and effective treatment and preventive strategies, are based on understanding the characteristics of the most common pathogens that occur on a particular farm. On a practical basis, microbiological examination of milk is used to help the veterinary practitioner answer the following questions:

- Do cows have subclinical mastitis caused by contagious mastitis pathogens?
- Is a clinical case of mastitis caused by a pathogen that is expected to respond well to intramammary antimicrobial therapy?
- Are the mastitis control strategies directed at the proper points of exposure for the most prevalent mastitis pathogens?
- Is mastitis caused by a "new" type of pathogen for this farm?

Table 18.5. Key performance indicators and sources of typical bacteria used to troubleshoot problems with bacteriological quality of raw bulk milk

Indicator	Type of bacteria detected	Common sources	Suggested goal
Standard plate count	Quantifies most viable, aerobic bacteria found in milk	Contamination during milking; problems with milk cooling; cleaning failures	<10,000 cfu/mL
Laboratory pasteurized count	Thermoduric bacteria (e.g., bacillus and clostridia)	Biofilm development on milking equipment as a result of cleaning failures; occasional problems with contamination	<200 cfu/mL
Preliminary incubated count	Psychrotrophs (e.g., pseudomonas and others)	Contamination during milking; cooling problems	<10,000 cfu/mL
Coliform count	Coliform bacteria (e.g., *Escherichia coli* and *Klebsiella*)	Contamination during milking; rarely mastitis	<100 cfu/mL

Microbiological Analysis of Bulk Tank Milk

Microbiologic examination of bulk tank milk is a standard element of mastitis control programs and is the first step in the development of a milk quality plan. Bulk tank cultures (BTC) are often used to screen for mastitis pathogens in herds (or groups) of lactating dairy cows. The methodology of performing BTC varies immensely among labs. The sampling interval, sample collection, microbiological methods, and report format have not been standardized, and it is difficult to compare results among laboratories. To ensure that diagnostic test results will be useful, veterinarians should submit bulk tank milk samples to a single, specialized laboratory that uses methodologies that include plating dilutions of milk and the use of selective media for isolating and counting bacterial colonies. Protocols for bulk tank culturing can be found at the NMC website (www.nmconline.org). In most instances, milk quality laboratories should include screening for mycoplasma spp. in their normal diagnostic protocols.

The interpretation of BTC results can be confusing because isolates can arise from subclinical mastitis infections, or from failure to exclude milk obtained from cows with clinical mastitis from the bulk tank, as well as from environmental contamination of milk. The best use of results of BTC is to identify herds that have cows subclinically infected with contagious mastitis pathogens (such as *S. aureus*, *M. bovis*, or *S. agalactiae*)

In almost all instances, the occurrence of these pathogens in bulk tank milk is highly predictive of the presence of infected cows within the dairy herd (Wilson & Gonzalez, 1997). However, the failure to isolate pathogens from bulk milk *does not* indicate that infected cows are not present in the herd, as the test is not very sensitive, and it is not unusual to identify infected cows in spite of an apparently negative BTC (Fig. 18.5). Likewise, the number of organisms isolated does not correspond to the prevalence of infected cows in the herd, and comparisons of colony counts before and after implementation of a control strategy should not be used to assess response to interventions.

Interpretation of BTC results must be performed by considering characteristics of the individual organisms that are recovered from the milk. Typical KPI for evaluating BTC reports are available (Table 18.6), but the scientific validity of the recommendations have not been well documented. Pathogens found in bulk milk samples can originate from infected udders, teat skin, or contamination during milking. Non-agalactiae *Streptococci* are usually present in the environment of the cow. While shedding of bacteria from subclinical infections can contribute to excessive numbers of environmental *Streptococci*, poor premilking hygiene should always be investigated when excessive numbers of these organisms are found, especially when the BTC results also indicate excessive numbers of coliform bacteria. The natural duration of intramammary infections caused by coliform organisms is short; therefore, excessive numbers of coliforms suggests poor premilking hygiene or environmental contamination. As is typical for all diagnostic tests, confidence in the results increases when the test results are repeatable. When an unusual result of a BTC is found, the first step should be to repeat the test to verify the diagnosis. The submission of bulk tank milk samples that have been independently collected for four consecutive days and submitted together is recommended by many laboratories to increase the sensitivity (Farnsworth, 1993). In most laboratories, the samples will be commingled and processed as one sample to reduce costs.

Date of Samples 2/17/18/19/20/21/22 Field Associate Randy

PreMMAP® ☐ 90 Day ☐ 180 Day ☐ Other ☒

Number of Samples: 1 ☐ 3* ☐ 6 ☑ (*commingled)

Routine Culture Only ☐ Routine and Mycoplasma ☒ Mycoplasma Only ☐

CULTURE RESULTS:

Bacteria Isolated	None	Colony Count Low	Medium	High	Significance Low	High
CONTAGIOUS						
Streptococcus Agalactia	____	<50	50-200	>200	____	____
Staphlococcus Aureus	____	<50	50-150	>150	____	____
Mycoplasma Bovis	(C)	1	2-5	>5	____	____
ENVIRONMENTALS						
Streptococcus Species	____	<500	500-1200	>1200	____	____
Staphlococcus Species	____	<300	300-500	>500	____	____
Coliforms	____	<100	100-400	>400	____	____
Contaminated Sample	____	Retest Immediately!				

(a)

Sample #	Cow #	Contagious: Strep Ag	Staph Aureus	Mycoplasma	C. Bovis	Environmentals: Strep Species	Staph Species	E. Coli	Coliforms	Klebsiella	A. Pyogenes	Contaminates: Level 1-Reculture	Level 2-Reculture	No Growth	Comments
1	LR 8306			2											
2	LF 9817			2											
3	All 9952			2											
4	RLF 5620			2											
5	All 9949			2											
6	All 3950			2											
7	LF 9810			2											
8	All 277			2											
9	RR 6575			2											
10	LR 5834			2											
11	LF 8596			2											
12	All 8185			2											
13	LR 6382			2											
14	RR 7691			2											
15	LR 9171			2											
16	LR 6875			2											
17	LR 8514			2											
18	RR 7406			2											
19	LR 9671			2											
20	RR 8478			4											
21	RR 4091			2											
22	RR 5555			2											
23	RR 7032			2											
24	LR 9737			2											
25	LR 8553			2											

(b)

Figure 18.5. Comparison of bulk tank culture results for mycoplasma (a) and results of individual cow milk samples (b) obtained on one farm in the same period. Note the false negative bulk tank report.

Microbiological Analysis of Quarter Milk Samples

Microbiological examination of milk samples is an important and underused aspect of mastitis control. While microbiological examination of milk samples is often considered to be the gold standard for identification of infected quarters, negative results (no growth of bacteria from samples of animals suspected to be infected) are a common outcome. No bacteria were isolated from approximately one-third of milk samples submitted to a major mastitis laboratory in Wisconsin between 1994 and 2001; the proportion of negative results increased from 23% to 50% (Makovec & Ruegg, 2003b). Potential reasons for negative results include a decrease in the amount of mastitis caused by high-shedding organisms (such as *S. agalactiae*), an increased amount of mastitis caused by organisms that do not grow using routine laboratory procedures (e.g., *M. bovis*), and the use of insensitive sampling methods and laboratory techniques. The probability of recovering pathogens can be improved by taking extra care during

Table 18.6. Key performance indicator (KPI), sources, and suggested interpretation of bulk tank milk culture results[a]

Bacteria	Goal (cfu/mL)	Typical sources in milk	Interpretation
Streptococcus agalactiae	0	Mastitis infections	Isolation of any colonies indicates likely presence of infected cows
Staphylococcus aureus	0	Mastitis infections, teat skin	For both pathogens, isolation from bulk tank milk indicates the likely presence of infected cows; repeated isolation in bulk tank milk usually found in herds with greater prevalence
Mycoplasma spp.	0	Mastitis infections	
Coagulase-negative Staphylococci (CNS)	<250–500	Teat skin contaminant	Investigate premilking teat disinfection
Environmental streptococci	<500	Contamination from dirty udders or milking equipment; occasionally caused by mastitis infections	When environmental streptococci and coliforms both exceed goals, it is a strong indication that the source was poor milking hygiene.
Coliforms	<100		
Others	0	*Pseudomonas* spp.	Presence of significant numbers often indicates contamination of milk with water
	0	*Bacillus* spp.	Presence of significant numbers often indicates poor milk sample handling

[a]Adapted from Farnsworth (1993) and Jayarao et al. (2004).

sampling to avoid contamination and by collecting milk only from quarters that have increased SCC (detected by use of CMT or other cow-side SCC test). To ensure that meaningful data will be obtained from milk samples taken from cows with suspected subclinical infections, veterinarians should advise their clients to submit at least 25 separate quarter samples.

Diagnostic tests (such as milk cultures) are most useful in production medicine programs when results are closely linked to management decisions. Most traditional technologies (such as submission of milk samples) require sending milk samples to a remote laboratory. These methods are often criticized as too slow for on-farm decision making. Anecdotal data suggest that many farmers have not adopted culturing of milk samples because they do not know how to use the results or fail to recognize the economic value of the decisions that are made as a result of the test. Results of milk culturing can be very useful to identify mastitis pathogens and to make management decision about treatment, culling, segregation, and disease prevention. The development of on-farm culture (OFC) programs has provided a way to rapidly link test results to important management decisions. The use of OFC results for direct treatment of clinical mastitis (see next section) gives farmers the opportunity to make better treatment decisions and reduce costs associated with milk discard (Neeser et al., 2006). On-farm culturing is often used to appropriately target intramammary antimicrobials toward appropriate cases and to help determine the appropriate duration of therapy (Fig. 18.6). In general, upon diagnosis of a clinical case of mastitis, the cow is examined by farm personnel and a milk sample is obtained. If the case is scored as a grade 1 or 2 (the cow is not sick), then no antimicrobial treatment is given until results of OFC are known (generally24 h). The most basic method of OFC is the determination of gram-positive versus gram-negative pathogens. This method may be appropriate when contagious mastitis is considered unlikely (very few infections caused by *S. aureus* or *Mycoplasma* spp. mastitis). In this instance, appropriate intramammary antimicrobials are used to treat gram-positive infections, and no antimicrobials are used for treatment of gram-negative infections. Mastitis on some farms is caused by a more diverse mix of pathogens and may require the diagnosis of *Streptococci* spp. (for extended intramammary therapy) or *S. aureus* (for extended intramammary treatment of selected infections, and culling, dry-off of the quarter or segregation of chronic infections). In these instances, more sophisticated culture systems may be required.

A variety of selective media is used in OFC to come to a presumptive diagnosis and direct treatment (Fig. 18.7). The most common medium used in OFC systems include: (1) blood agar—a nonselective medium that grows most mastitis organisms; (2) MacConkey agar—a selective medium that grows only gram-negative organisms; (3) TKT agar—selective for *Streptococci*;

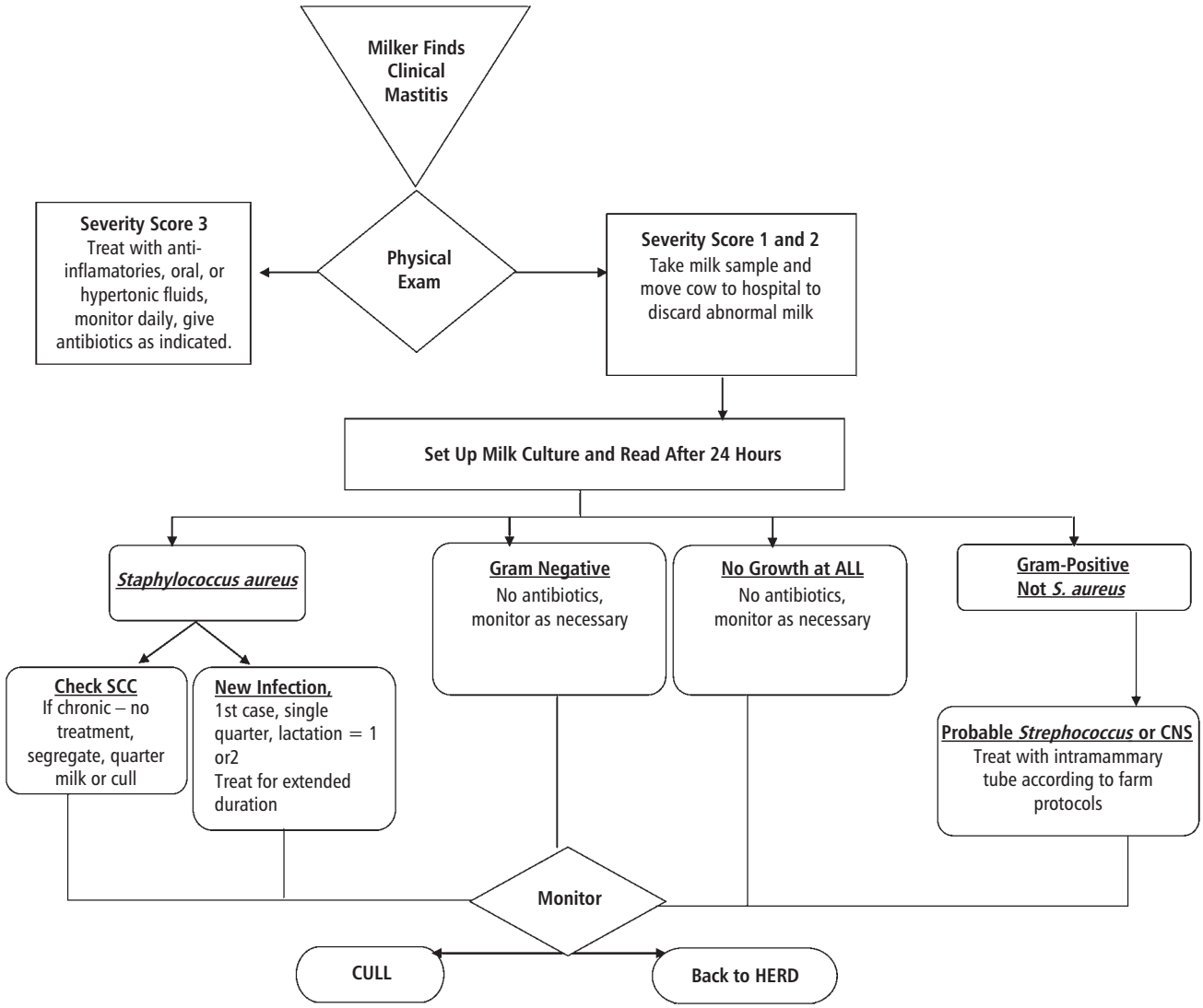


Figure 18.6. Typical on farm culture-based treatment protocol (adapted from Hess et al., 2003).

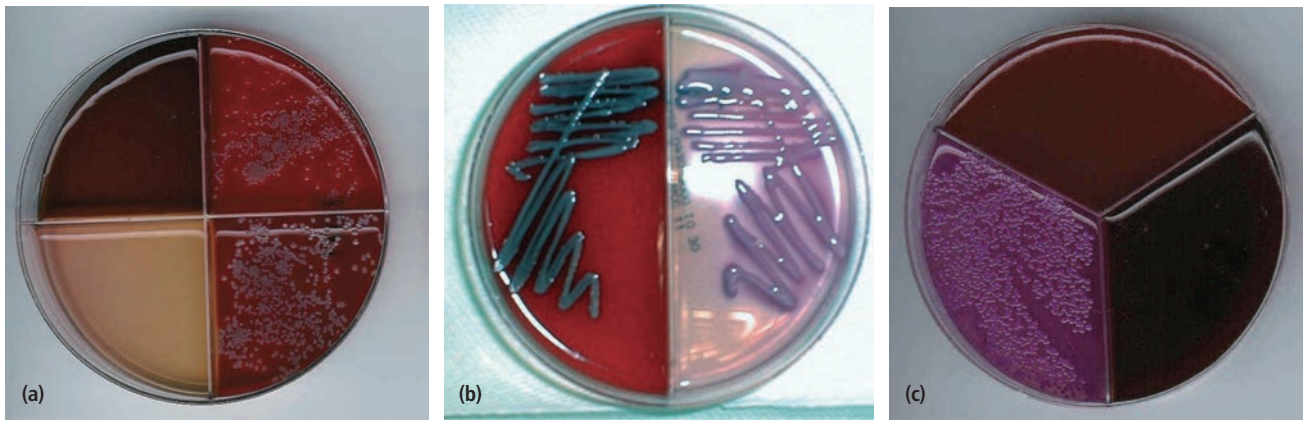


Figure 18.7. Examples of mastitis pathogens growing on selected types of on-farm culture media. (a) *S. aureus* growing on blood agar, and factor agar media section of a quadplate that also contains MacConkey and MTKT media. (b) *Klebsiella* spp. growing on both sections of a biplate containing MacConkey and blood agar sections. (c) *E. coli* growing on MacConkey section of a triplate also containing factor and TKT agar.

(4) Baird-Parker or KLMB media—selective for *Staphylococcus* spp. Commercially available OFC systems include plates that are divided into several sections with different media (Fig. 18.7). The Bi-plate system is a plate with two different types of agar. Biplates usually include MacConkey agar on one-half of the plate to selectively grow gram-negative organisms, while the medium on the other half of the plate will grow most aerobic organisms. Alternately, the Tri-plate system is a culture plate with three different types of agar: in addition to including MacConkey agar (gram-negative growth) and Factor agar (gram-positive growth), it may include a section of MTKT agar, which is selective for *Streptococci*. Additional chromogenic media are also commercially available which may allow discrimination among additional pathogens.

Development and oversight of an OFC program is an ideal way for the production medicine veterinarian to increase involvement in mastitis control programs and improve treatment protocols. Some veterinary practices increase their involvement by offering complete technical support for OFC systems, using a veterinary technician to restock supplies, train farm personnel, and provide oversight of quality control. In areas that have many small herds, it is possible for veterinary clinics to provide a similar system by having the producer promptly drop milk samples off at the clinic and withhold treatments until the microbiological results are known. After 24 h, the culture result and appropriate treatment protocol can be faxed or emailed to the producer.

Several studies that have evaluated a variety of selective media have indicated that OFC systems appear to be about 80% accurate in differentiating gram-positive and gram-negative pathogens (Lago et al., 2005; Hochhalter et al., 2006; Pol et al., 2009; Rodrigues et al., 2009). The use of OFC to make more specific pathogen diagnoses is likely not as accurate and requires additional training of personnel and oversight.

Ensuring Effective and Judicious Use of Therapeutics Used for Treatment of Mastitis

A successful production medicine program occurs when there is a strong relationship between the veterinarian and dairy producer and is predicated on the ability of the veterinarian to positively influence farm management. Dairy cows (rather than beef animals) account for a large majority of antimicrobial residue violations detected in meat, and many of those residues are associated with the use of veterinary prescription drugs. On a societal level, supervising usage of antimicrobials and other drugs is one of the most important roles that the production medicine veterinarian can assume. This role is especially important for mastitis treatments because they account for the majority of antimicrobial usage on most farms and because most cases of mastitis are not examined nor treated by veterinarians. The ability of veterinarians to develop appropriate treatment protocols is based on development and evaluation of treatment records. As a minimum, farmers should be encouraged to record case severity, drug used, number of days treated, probable diagnosis (probable pathogen or Gram status), date that meat and milk are suitable for marketing, and follow-up information such as date culled or date of recurrence. The average number of days that milk is discarded for mastitis treatment (Table 18.3) is a KPI that veterinarians should routinely monitor to assess compliance with treatment protocols. The selection of antimicrobials for treatment of mastitis must be based on a presumptive diagnosis of the type of pathogen that is most likely responsible for the infection and cow-and herd-specific factors. Practitioners who work with certified organic dairy herds should be aware of which substances are allowed under national organic standards and also understand that extra-label drug usage is only allowed for approved human or veterinary health products (not for nonapproved remedies).

Guidelines for judicious use of antimicrobials have been published by the FDA (www.fda.gov), AVMA, and AABP. It is important that practitioners periodically recheck which antimicrobials are approved for extra-label usage. For example, FDA guidelines specify that there are no approved extra-label usages for any sulfonamides, which means that even though some sulfa drugs are approved for use in lactating cows, this class of drug may not be used for any mastitis treatments. In general, judicious use guidelines stress preventive health management, involvement of the practitioner in the development of effective treatment protocols, and thorough knowledge of both extra-label drug regulations and on farm compliance with those regulations. Veterinarians involved in production medicine programs should ensure that they can answer the following questions for each of their clients:

- Who is responsible for making treatment decisions on the farm and are they properly trained?
- Are written treatment protocols up to date and does the farm fully comply with them?
- How many animals receive treatments each month?
- Where are drugs purchased and who writes prescriptions?

- How are withholding times for meat and milk established?
- Does the farm have adequate documentation for extra-label drug usage?
- Does the practitioner adequately document all extra-label drug usage that they authorize?
- Has the farm been notified of any drug residues in meat or milk?

Implementing Effective Practices that Reduce Exposure to Mastitis Pathogens

Mastitis control is based on reducing exposure to mastitis pathogens. In general, high-quality milk is produced when cows are housed in a clean and dry environment and gently milked using practices that favor teat health and minimize exposure to contagious mastitis pathogens. To effectively prevent mastitis, production medicine practitioners should begin by reviewing the following issues:

- Do cow housing areas (including housing for dry cows) provide clean and dry environments for all stages of the lactation cycle?
- Are the udders clean enough and are teat ends healthy?
- Is the milking system properly calibrated and functioning properly?
- Does the milking routine incorporate currently recommended best management practices?
- Are milking technicians adequately trained?

Providing a Clean and Dry Environment

On many farms, milking technicians are assumed to have primary responsibility for mastitis control while other farm workers are responsible for stall maintenance and feeding. Many opportunities for exposure to mastitis pathogens occur outside of the milking facility, and all employees who have the ability to influence exposure to pathogens should be aware of the importance of mastitis control and share accountability. Contact with moisture, mud, and manure in cow housing areas can influence the rate of clinical mastitis and the veterinarian should be familiar with environmental hygiene in all stages of the lactation cycle. Rapid movement of animals for handling or milking often results in splattering of manure onto udders.

Overcrowding can concentrate excessive manure in areas designed for fewer animals. Manure handling, type of bedding, and maintenance of cow beds all have major impact on cows and udder hygiene. Research has demonstrated that herds with greater bulk milk SCC often have less satisfactory hygienic practices as compared to herds with lower bulk milk SCC (Barkema et al., 1998). For example, 31% of herds with bulk milk SCC >250,000 cells/mL were categorized as having "dirty milking parlors" as compared to 15% of herds with bulk milk SCC < 150,000 cells/mL (Barkema et al., 1998). Herds with SCC > 250,000 cells/mL also had more stalls containing >10% manure (19% vs. 12%), stalls cleaned less frequently (1.6 vs. 2.2 times/day), and less use of bedding in stalls (Barkema et al., 1998).

Bedding management can be a primary determinant of bacterial numbers on teat ends. The amount of moisture and bacteria that are present in cow bedding are especially important (Hogan et al., 1989; Hutton et al., 1990; Zdanowicz et al., 2004). Organic bedding materials tend to support more bacterial growth as compared to inorganic bedding materials, but significant exposure to *Streptococci* spp. and *Klebsiella* spp. may also occur when sand bedding is used. A linear relationship between the rate of clinical mastitis and the number of gram-negative bacteria in bedding has been demonstrated (Hogan et al., 1989). This relationship is especially evident for *Klebsiella* species. A strong linear increase in clinical mastitis was noted as the number of *Klebsiella* colonies increased above 100 cfu/gram of bedding (Hogan et al., 1989). Greater organic matter and moisture in bedding can support large numbers of bacteria. Sand bedding that contains less organic matter usually has the least bacterial populations, but management processes that increase moisture content or the amount of organic matter in sand can increase growth of potential mastitis pathogens. Excellent hygienic standards for housing and milking centers should be a goal of all dairy farms. Dirty facilities increase the risk of mastitis and exposure to other pathogens. Clean, well-kept facilities not only reduce mastitis, but they help to instill pride in workers and are tangible evidence of commitment to quality.

Evaluating Animal Hygiene

Feeding high concentrate diets has been associated with looser feces and reductions in cow and facility cleanliness (Ward et al., 2002). Several studies have identified relationships between cow cleanliness and measures of milk quality (Barkema et al., 1998; Reneau et al., 2003; Schreiner & Ruegg, 2003). A scale of 1 (cleanest) to 5 (dirtiest) was used to score five separate areas of cows and was compared to linear somatic cell scores obtained from the same animals (Reneau et al., 2003). Cleanliness of the tail head, flank, and belly were not associated with somatic cell scores (SCS), but SCS of cows with cleaner udders and lower rear legs was less than SCS of cows with dirtier udders and legs, indicating that dirty cows

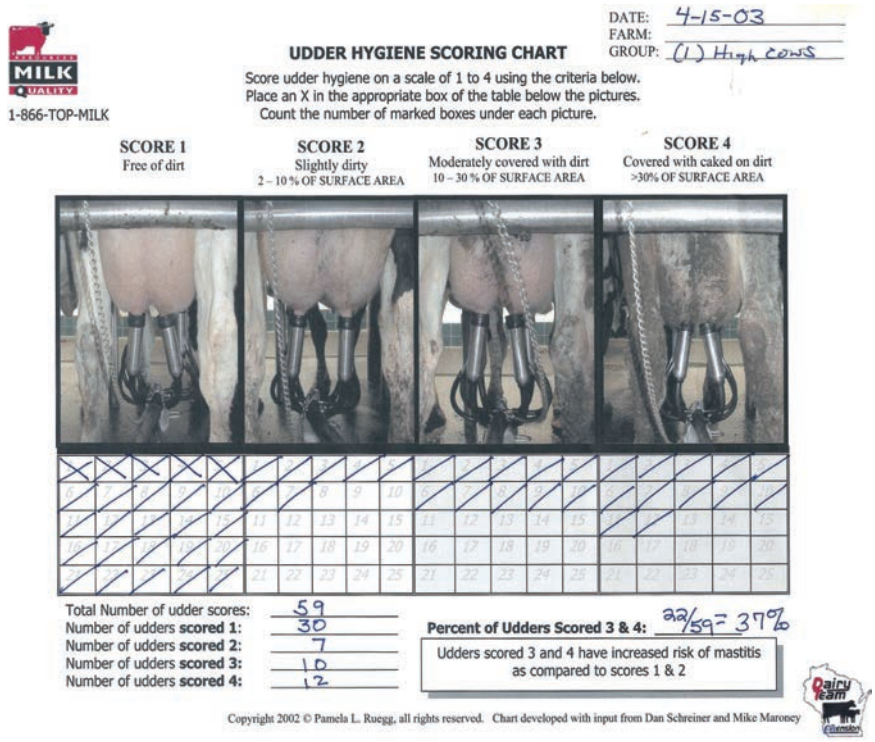


Figure 18.8. Udder Hygiene Chart—available at www.uwex.edu/milkquality/PDF/UDDER%20HYGIENE%20CHART.pdf.

had greater prevalence of subclinical mastitis (Reneau et al., 2003). A visual scoring system (Fig. 18.8) can be used by veterinary practitioners to score udder hygiene (UHS) either during milking or during the performance of other tasks that require the cows to be restrained (such as rectal palpation). No more than 20% of the herd should be categorized as having "dirty udders" (UHS of 3 or 4) (Schreiner & Ruegg, 2003). Cows with dirty udders have been shown to be more likely to have greater SCC and an increased risk of mastitis (Schreiner & Ruegg, 2003). Hygiene scores of udders should be routinely performed as a quality control measure just as body condition scores are performed to monitor nutritional management.

Managing the Milking Process

A consistent method of premilking sanitation and uniform attachment of properly functioning milking machines are both fundamental processes that help ensure production of high-quality milk. While most dairy veterinarians are not comfortable assuming primary responsibility for milking parlor design or maintenance of milking equipment, knowledge of basic milking equipment function is essential. Appropriate testing of milking equipment requires specialized equipment and should follow procedures that have been defined by the NMC (NMC, 2007). Some production medicine veterinarians may wish to invest in equipment such as air flow meters, digital vacuum recorders, and specialized milk flow meters while others may be more comfortable interpreting reports produced by milking-equipment service professionals. An appropriately designed mechanical milking system will provide stable partial vacuum and effective compression at the teat end to rapidly remove milk without causing congestion. There are a number of measurements that can be performed to investigate air flow, pulsation characteristics, and vacuum level. When initiating an investigation of milking machine function, KPIs include average claw vacuum and maximum claw vacuum fluctuation. Practitioners should ensure that all pulsators are properly functioning and are calibrated to provide sufficient duration of the massage phase of the pulsation cycle. Tests of milking equipment should be performed during milking time as part of scheduled maintenance program, when changes are made to the milking system and whenever farm conditions indicate the need to improve milking performance or mastitis control.

The objective of milking management is to ensure that teatcups are applied to visibly clean, well-stimulated teats, milk is rapidly and efficiently harvested, and milking units are removed when milking is completed. Deciding how many cows each operator will prepare prior to unit attachment is a key decision in designing an appropriate parlor work routine. A number of parlor

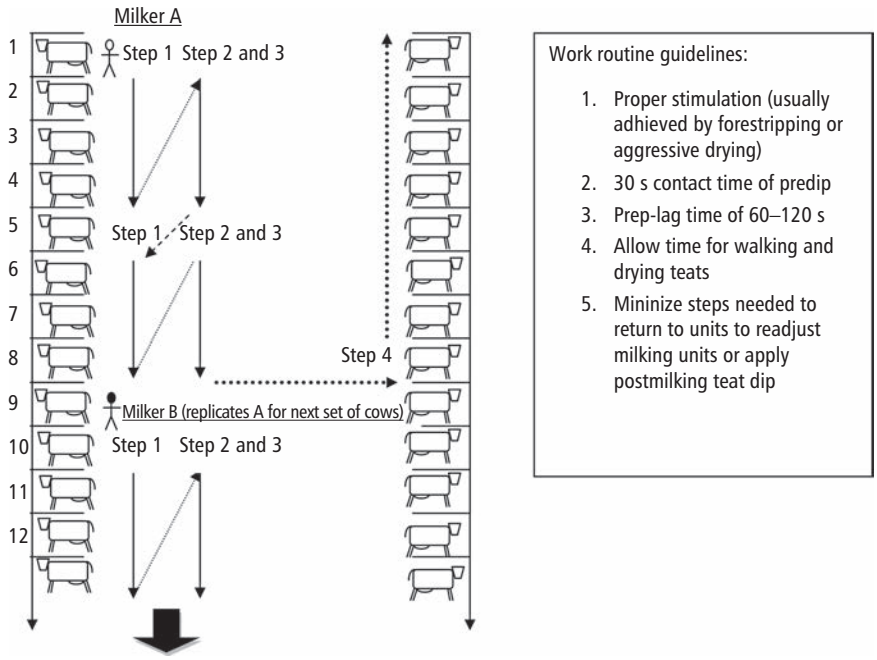


Figure 18.9. Typical territorial style milking parlor work routine that includes a complete milking routine and allows for proper timing (these routines assume that milking units are detached automatically). The number of stalls per worker will vary depending on parlor design, number of milking technicians and number of milking stalls. Step 1 includes application of premilking teat disinfectant and forestripping; Step 2 includes drying with an individual single use paper or cloth towel; Step 3 attaches the milking unit; Step 4 includes application of the postmilking teat dip after automatic detachment of the unit.

work routines can be successfully used as long as they meet the principles of good milking practices. Several common routines have been developed that utilize groups of three to four cows to ensure that prep-lag times and predip contact time are optimized (Fig. 18.9). When designing a parlor work routine, important principles include providing sufficient contact time for the premilking teat disinfectant to be effective, allow time for removal of foremilk and thorough drying of teats, attaching the milking unit within an interval that maximizes milk letdown, extracting milk before milk flow diminishes, and ensuring that postmilking teat disinfectants are properly applied to all teats.

Consistent use of good milking practices is essential to control mastitis. As part of the milk quality plan, production medicine practitioners should routinely observe the milking process and be prepared to evaluate compliance with KPI for milking performance (Table 18.7). Several components of the milking process merit special attention.

a. *Premilking teat disinfection.* Methods of premilking teat preparation have been extensively studied (Galton et al., 1984, 1986; Pankey, 1989; Ruegg & Dohoo, 1997). There is no question that the most effective method to disinfect teats is to predip using an effective disinfectant. Predipping using iodine has been demonstrated to reduce SPCs and coliform counts in raw milk by five- and sixfold, respectively, as compared to other methods of premilking udder preparation (Galton et al., 1986). Effective predipping also contributes to improvements in food safety. Predipping has been shown to reduce the risk of isolation of *Listeria monocytogenes* from milk filters obtained from New York dairy herds by almost fourfold (Hassan et al., 2001). For effective reduction in bacterial numbers, the disinfectant must be in contact with teat skin for sufficient time to adequately kill bacteria. Teat dips must be properly formulated, stored in clean containers, completely applied to debris free teats, and allowed sufficient time (usually at least 30 s) for action before removal.

b. *Examination of foremilk.* The examination of milk before attaching milking units is useful to ensure that abnormal milk is diverted from the human food chain and to identify cases of clinical mastitis at an early stage when the only symptom may be mildly abnormal milk. Forestripping is adequately performed when two to three streams of milk are expressed and is an effective means to stimulate milk letdown. When both predipping and forestripping are practiced, there is no data that indicate that the order that the steps are performed will affect milk quality (Rodrigues et al., 2005). Milking technicians should

Table 18.7. Selected key performance indicators (KPIs) for milking systems and milking performance

Source	Indicator	Suggested goal
Milking machine	Average claw vacuum	10.5–12.5″ Hg (35–42 kPa)
	Maximum claw vacuum fluctuation	<3″ Hg (<10 kPa)
	Average milk flow	5–9 lb/min (2.3–4.1 kg/min)
	Use of manual mode of milking (when automatic detachers are used)	<5% of milkings
	"D" phase of the pulsation cycle	At least 150–200 ms
Milking process	Premilking teat dip contact time	30 s before dry-off[a]
	Prep-lag time (time from stimulation to milking unit attachment)	60–120 s
	Milking unit attachment time	3–8 min (depending on milk production)
	% of teats with at least 75% coverage with postmilking teat dip	>90%

[a]Some product characteristics may allow for more rapid bacterial kill; label instructions for products with published research data should be followed.

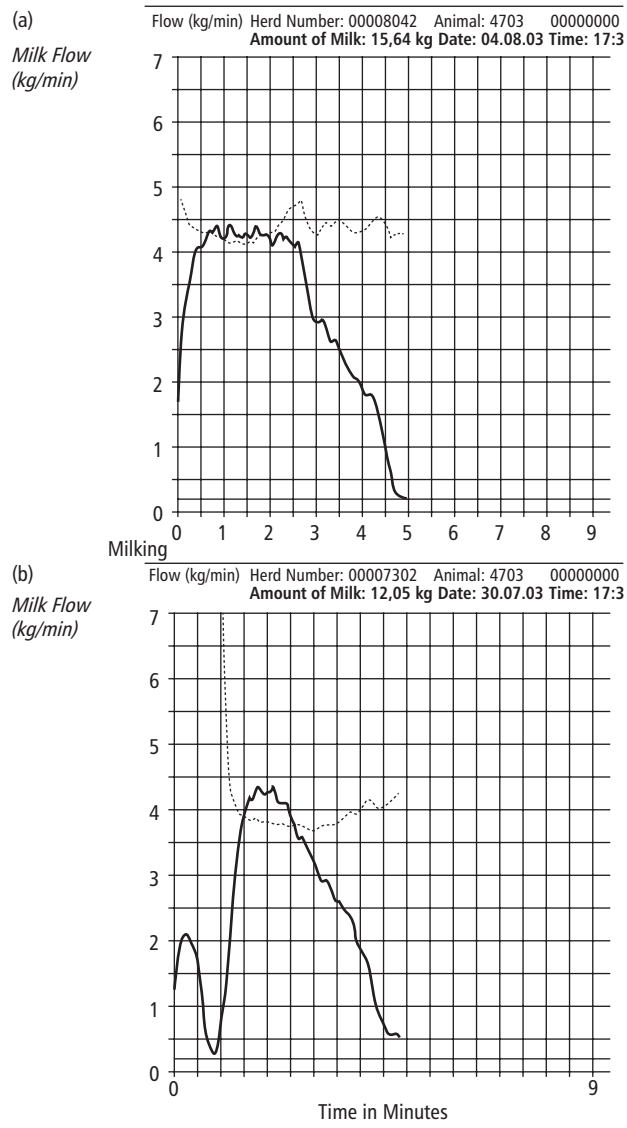


Figure 18.10. Milk flow curves for a dairy cow. (a) Typical milk flow curve for a cow experiencing normal milk letdown. (b) Bimodal curve indicating attachment of milking unit before milk letdown. Some cows may normally experience bimodal flow even after adequate stimulation.

be encouraged to wear disposable nitrile or latex gloves to reduce the potential spread of mastitis pathogens by contaminated hands.

c. *Drying of Teats.* Effective drying of teats is probably the most important step to ensure hygienic teat preparation. Drying of teats has been demonstrated to reduce bacterial counts of teat ends from 35,000 to 40,000 cfu/mL for teats that were cleaned but not dried to 11,000–14,000 cfu for teats that were dried using a variety of paper towels (Galton et al., 1986). A single dry cloth or paper towel should be used to dry teats of each cows. The use of a single towel to dry udders on more than one cow has been associated with a greater monthly rate of clinical mastitis (7.8% for herds that used 1 towel/cow vs. 12.3% for herds that used towels on >1 cow; Rodrigues et al., 2005).

d. *Attaching the milking unit.* One objective of the milking routine is to attach the milking unit to well-stimulated cows that have achieved milk letdown, thus maximizing milk flow (Fig. 18.10a). The time period between stimulation of the cow and unit attachment is often referred to as the "prep-lag" time. A number of studies have been performed to determine the optimal prep-lag time (Rasmussen et al., 1992; Maroney et al., 2004). It is well recognized that the need for stimulation varies depending on yield, stage of lactation, milking interval, and breed (Bruckmaier, 2005). Historically, a prep-lag time of 45–90 s has been recommended, but negative consequences (reduced milk yield) have not been reported until lag times have exceeded 3 min (Rasmussen et al., 1992; Dzidic et al., 2004; Maroney et al., 2004). The failure to achieve adequate milk letdown will often result in bimodal milk flow (Fig. 18.10b), and the

application of the milking unit without stimulation or immediately after stimulation should be discouraged. It appears that prep-lag times longer than 90 s will not be uniformly detrimental but premature attachment of the milking unit should be avoided (Dzidic et al., 2004; Maroney et al., 2004).

e. *Managing cows postmilking.* Postmilking teat antisepsis was initially developed to reduce the transmission of contagious mastitis pathogens and is based on killing bacteria that are present in milk that remains on teat skin after milking has been completed. Postmilking teat dipping is one of the most highly adopted practices in the dairy industry, and it is the final hygienic defense against infection after milking is completed. While teat dipping is universally recognized as a useful practice, effective implementation of teat dipping is often variable. To maintain excellent hygienic standards and minimize mastitis, continued education of milking technicians about the principles of mastitis control is often necessary. Evaluation of the effectiveness of postmilking teat dipping is best performed when milking technicians are not aware of the evaluation. When colored teat dips are used, one effective method of evaluation is to surreptitiously score teats of cows in the return lanes after milking. If possible, teats from at least 20 to 30 cows should be examined, and the goal is to observe complete coverage (75%) of at least 95% of observed teats. Digital photographs of well-covered and inadequately covered teats are an excellent training tool that can be used to demonstrate proper teat dipping (Fig. 18.11).

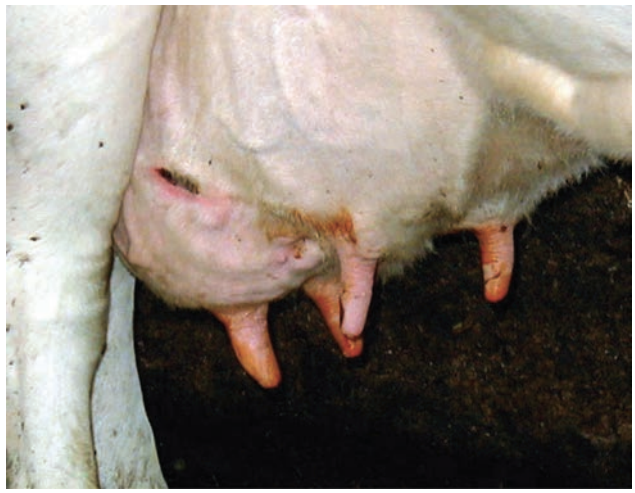


Figure 18.11. Photograph of inadequate teat dip coverage. Photographs of teat dip coverage should be routinely obtained in the return alleys as the cows exit the milking parlor and used to monitor and retrain milking technicians.

Training Milking Technicians

Implementation of standardized milking processes can be difficult because most farms use several milking technicians, and some technicians have little experience or training. Helping to communicate expectations to employees and providing training is a potential role for production medicine veterinarians. Statistics from larger Wisconsin farms (average herd size of 400 cows) indicate that while the use of recommended milking practices was generally high, management of the milking parlor was often neglected (Rodrigues et al., 2005). Training of milking technicians occurred relatively infrequently with only 22% of the farmers indicating that they held frequent training sessions for milking technicians, while 49% indicated that they trained technicians only at hiring and 29% indicated that no training was provided. It is difficult to understand how employees are expected to perform adequately because less than half (41%) of the farms reported that they had a written milking routine. In this study, farms that reported more frequent training of technicians reported greater parlor throughput and less clinical mastitis (Rodrigues et al., 2005).

Managing Nonlactating Heifers and Cows to Reduce Exposure to Mastitis Pathogens

Replacement Animals

Dairy practitioners working to improve milk quality should not neglect the oversight of heifers because mastitis infections can occur prior to the initiation of lactation. Dairy heifers may become subclinically infected with mastitis pathogens before calving (Oliver & Mitchell, 1983). In some studies, bacteria have been isolated from more than 50% of quarters of prepartum heifers, but considerable variation among farms has been described (Oliver & Mitchell, 1983; Trinidad et al., 1990; Fox et al., 1995). *Staphylococci* (primarily coagulase-negative *Staphylococci* but also *S. aureus*) are the most frequent isolates recovered from heifers, but environmental pathogens have also been recovered (De Vliegher, 2004). SCCs of first lactation dairy cows should be very low (<150,000 cells/mL), and if greater than 10% of the first test SCC exceed this threshold, risk factors to determine the point of infection should be evaluated. Risk factors for infection include the feeding of mastitic milk to calves, and this practice should be discouraged unless the milk can be pasteurized prior to feeding. In some herds, the use of intramammary antimicrobial treatments administered during late gestation have been shown to be highly effective, and cure rates for staphylococcal infections frequently exceed 90% (Owens et al.,

2001; Oliver et al., 2003). The effect of precalving treatment on production of heifers appears to be variable among herds (Fox et al., 1995). Veterinarians should recommend this practice only for herds that have demonstrated problems with heifer mastitis.

Managing Dry Cows

The importance of the dry period in the control of mastitis is well-known, and veterinarians should monitor the effectiveness of strategies used to prevent exposure to mastitis pathogens during this period of the lactation cycle. During the dry period, the mammary gland experiences physiologic changes which result in increased susceptibility for development of new intramammary infections (Oliver & Sordillo, 1988). Both existing infections (from the previous lactation) and new infections (that originate between drying-off and the early postpartum period) contribute to the occurrence of subclinical and clinical mastitis in subsequent lactations (Green et al., 2007; Pantoja et al., 2009a,b). Mammary glands that become infected during the dry period produce less milk and are more likely to experience clinical mastitis in the subsequent lactation (Oliver & Sordillo, 1988; Pantoja et al., 2009a,b). Therefore, the veterinarian must include methods to monitor and manage exposure to mastitis pathogens during this critical period. The use of SCC to monitor subclinical mastitis is valuable for assessing overall udder health in the dry and postpartum period. When using SCC values, veterinarians should recognize that SCC values determined within the first 5 days postpartum are not necessarily predictive of infection, and the SCC of many mammary quarters that appear infected immediately after calving often return to normal within a few days. Veterinarians can monitor SCC at first DHIA test to assess the effectiveness of management of the dry and postpartum period (Table 18.4). It is especially important to monitor cows that have high SCCs at both dry-off and at the next calving (chronic subclinical infections). Quarters that remain with increased SCC across the dry period are four times more likely to have a case of clinical mastitis in early lactation as compared to quarters with lower SCC (Pantoja et al., 2009a).

Management of the dry period is recognized as a critical component of udder health programs, and this is especially true for herds composed of a greater proportion of older cows. In one study, the rate of development of new intramammary infection during the dry period was 12% for cows of first parity in contrast to about 20% for older cows (Dingwell et al., 2002). It is thought that both existing subclinical infections and decreased patency of the teat sphincter may contribute to increased susceptibility to mastitis observed in older cows. Regardless of cause, herds that are composed of a larger proportion of mature cows need to especially focus on preventive strategies during the dry period. The veterinarian should regularly monitor risk factors for exposure to mastitis pathogens during the dry period, focusing particularly on environmental cleanliness, and ensure that intramammary dry treatments and other preventive strategies are properly implemented.

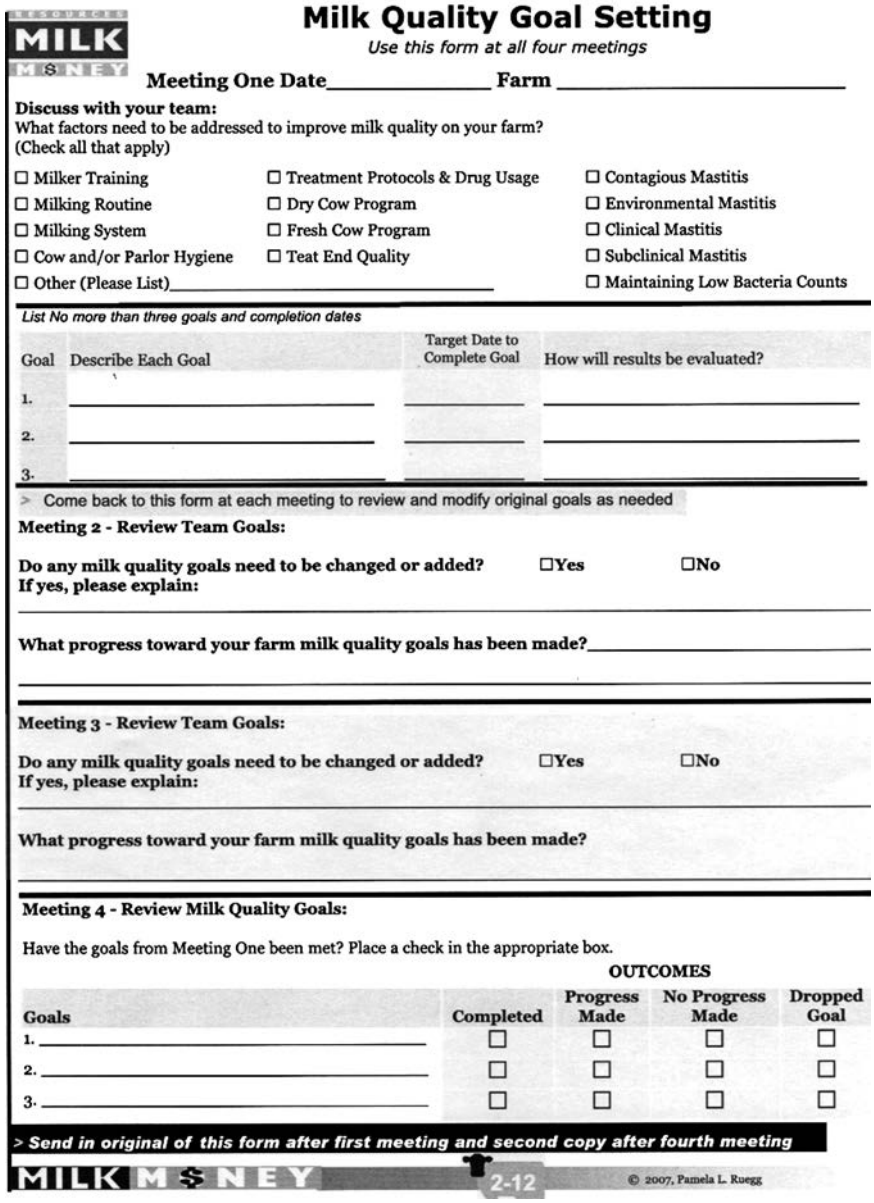
Many contagious mastitis pathogens cause subclinical infections, and the use of dry cow therapy is a well-established and cost-efficient method of eliminating existing subclinical mastitis infections. More recently, the importance of exposure to environmental pathogens during the dry period has been noted (Green et al., 2007). Exposure to both gram-negative (such as *E. coli* and *Klebsiella* spp.) and gram-positive (such as *Streptococcus* spp.) environmental pathogens may occur when management during the dry period is not optimal. It has been estimated that at least 8%–12% of quarters that do not receive dry cow therapy will become infected during the dry period (Eberhart, 1986). All conventional producers should be encouraged to administer properly formulated antimicrobial therapy at dry-off. The use of antimicrobials to treat all quarters of all cows has been questioned in recent years because of concerns about the development of antibiotic-resistant bacteria. However, there is no evidence that the use of dry cow therapy has contributed to the development of resistance to antimicrobials, and decreased resistance has been noted for some antibiotics (Erskine et al., 2001; Makovec & Ruegg, 2003a). There is strong evidence that cows that do not receive dry cow therapy develop more intramammary infections, even when the cows are uninfected before dry-off (Berry & Hillerton, 2002). The effectiveness of administration of dry cow therapy can be monitored by periodically checking the amount of drug left in the discarded intramammary infusion tubes. More than 95% of tubes should be completely empty.

Working with Other Professionals to Implement Best Management Practices

It is well-known that mastitis can be controlled by prevention of new infections and elimination of existing infections, but dairy farms are complex systems and implementation of a milk quality plan can be difficult unless all key influencers are in agreement. Surveys of veterinarians and other professionals who work with dairy producers indicate that barriers to improvement of milk quality are primarily related to motivation and implementation rather than lack of technical knowledge or skills (Rodrigues & Ruegg, 2004, 2005). In a survey of 165 Wisconsin dairy veterinarians and other

professionals, the existence of too many other problems (55%) and few incentives for production of high-quality milk (48%) were listed as the predominant reasons for failure of farms to improve milk quality. Only a few responders indicated that they felt the need for additional on-farm training (24%). For many farms, implementation of the milk quality plan is more successful when the veterinarian, other key professionals, and farm personnel work together on mutually agreed-upon goals.

Mastitis control programs often focus on enhancing adoption of research-based practices that reduce the level of exposure to mastitis pathogens. These programs are often more successful when they include farm-specific goals that are agreed upon by a consensus of the farm management team. In Wisconsin, a team-based milk quality program ("Milk Money") was designed to help individual dairy producers create targeted milk quality plans that focused on helping farmers define and reach realistic milk quality goals. (Rodrigues et al., 2005; Rodrigues & Ruegg, 2005). The voluntary program was designed to encourage the production of high-quality milk and was based on the formation of a self-selected team of advisors. The local veterinarian was a key member of almost all teams (88%). During the program, farmers met with their team at least four times (usually at four consecutive monthly meetings) to develop and implement a milk quality plan that addressed their own milk quality goals. The milk quality team and program materials were used to help set goals and prioritize management changes (Figs. 18.12 and 18.13). At



Milk Quality Goal Setting

Use this form at all four meetings

MILK M$NEY

Meeting One Date_____ **Farm** _____

Discuss with your team:
What factors need to be addressed to improve milk quality on your farm?
(Check all that apply)

☐ Milker Training	☐ Treatment Protocols & Drug Usage	☐ Contagious Mastitis
☐ Milking Routine	☐ Dry Cow Program	☐ Environmental Mastitis
☐ Milking System	☐ Fresh Cow Program	☐ Clinical Mastitis
☐ Cow and/or Parlor Hygiene	☐ Teat End Quality	☐ Subclinical Mastitis
☐ Other (Please List)_____		☐ Maintaining Low Bacteria Counts

List No more than three goals and completion dates

Goal	Describe Each Goal	Target Date to Complete Goal	How will results be evaluated?
1.			
2.			
3.			

> Come back to this form at each meeting to review and modify original goals as needed

Meeting 2 - Review Team Goals:

Do any milk quality goals need to be changed or added? ☐**Yes** ☐**No**
If yes, please explain:

What progress toward your farm milk quality goals has been made?_____

Meeting 3 - Review Team Goals:

Do any milk quality goals need to be changed or added? ☐**Yes** ☐**No**
If yes, please explain:

What progress toward your farm milk quality goals has been made?

Meeting 4 - Review Milk Quality Goals:

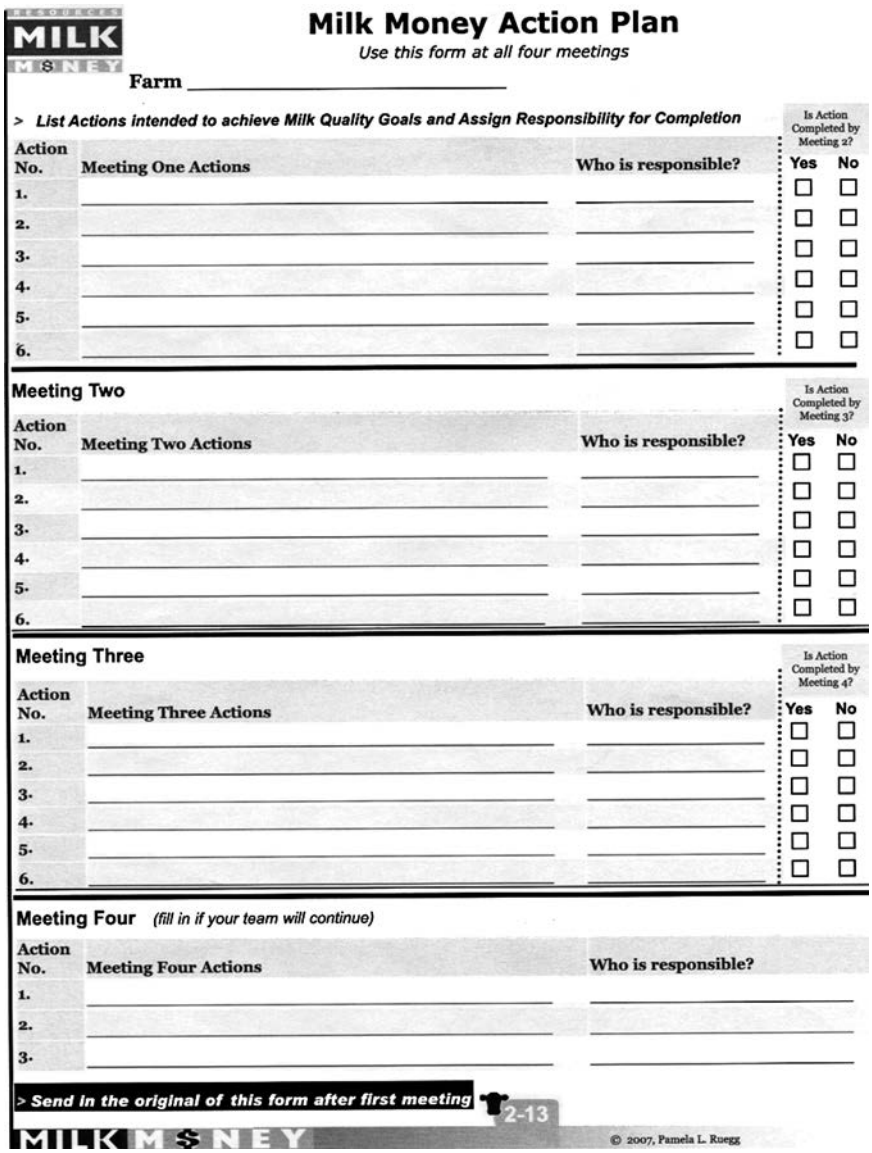
Have the goals from Meeting One been met? Place a check in the appropriate box.

	OUTCOMES			
Goals	**Completed**	**Progress Made**	**No Progress Made**	**Dropped Goal**
1. _____	☐	☐	☐	☐
2. _____	☐	☐	☐	☐
3. _____	☐	☐	☐	☐

> *Send in original of this form after first meeting and second copy after fourth meeting*

MILK M$NEY 2-12 © 2007, Pamela L. Ruegg

Figure 18.12. Example of a milk quality goal form that can be used to guide implementation of individual milk quality teams.



MILK MONEY

Milk Money Action Plan

Use this form at all four meetings

Farm _____

> *List Actions intended to achieve Milk Quality Goals and Assign Responsibility for Completion*

Action No.	Meeting One Actions	Who is responsible?	Is Action Completed by Meeting 2? Yes	No
1.			☐	☐
2.			☐	☐
3.			☐	☐
4.			☐	☐
5.			☐	☐
6.			☐	☐

Meeting Two

Action No.	Meeting Two Actions	Who is responsible?	Is Action Completed by Meeting 3? Yes	No
1.			☐	☐
2.			☐	☐
3.			☐	☐
4.			☐	☐
5.			☐	☐
6.			☐	☐

Meeting Three

Action No.	Meeting Three Actions	Who is responsible?	Is Action Completed by Meeting 4? Yes	No
1.			☐	☐
2.			☐	☐
3.			☐	☐
4.			☐	☐
5.			☐	☐
6.			☐	☐

Meeting Four *(fill in if your team will continue)*

Action No.	Meeting Four Actions	Who is responsible?
1.		
2.		
3.		

> *Send in the original of this form after first meeting*

2-13

MILK MONEY © 2007, Pamela L. Ruegg

Figure 18.13. Example of a milk quality action plan that can be used to implement and track progress of a milk quality plan.

each monthly meeting, a simple list of 1–6 actions to be completed before the next meeting was developed, people responsible for completing the actions were assigned, and a method of evaluating the outcome of the action was agreed upon (Fig. 18.13). At the beginning of each subsequent meeting, the action list was reviewed, and people were held accountable for completion of their tasks. After the conclusion of four meetings, the team reassessed their progress toward the goals and decided whether future meetings were necessary. This simple process was successful in encouraging adoption of best management practices and increased involvement of many dairy veterinarians in mastitis control programs. The percentage of farmers that indicated that they consulted their veterinarian about milk quality programs increased from 20% (before the program) to 84% (at the end of the four meetings) (Rodrigues & Ruegg, 2005). This process can be easily replicated by a motivated production medicine veterinarian, especially if a management team format is already in place. Analyses of herds that have completed the Milk Money program indicate that a team-based goal-oriented approach can result in rapid improvement in milk quality (Rodrigues & Ruegg, 2005).

All veterinarians work with some herds where efforts to improve milk quality always fail. In most instances, failure can be attributed to a lack of commitment to change. In one program where herds did not achieve their milk quality goals, a lack of time and other farm problems were reported as the major constraints to implementing the suggested changes (Hohmann, 2008). Implementation of a milk quality plan depends on the ability to

apply changes to the current farm situation and changing farm priorities. The ability of the veterinarian to lead and motivate farm personnel is critical to this effort.

Conclusion

The delivery of milk quality programs by veterinarians is an important overall component of a dairy production medicine program. Preventing mastitis and improving milk quality is a vitally important role that contributes to improved animal well-being, enhanced farm profitability, and better assurances that food is being produced in a safe and sustainable way. Veterinarians who deliver production medicine programs should seek out involvement in continuing education programs that focus on research-based methods and advancements in mastitis control. Milk quality programs must continue to advance with changes in pathogens, changes in milking equipment, and cow housing systems as societal expectations evolve.

Key Resources for the Production Medicine Veterinarian Working with Milk Quality

National Mastitis Council (NMC), www.nmconline.org

Key guides available from the NMC: NMC Laboratory Handbook on Bovine Mastitis.

Procedures for Evaluating Vacuum Levels and Air Flow in Milking

Troubleshooting Cleaning Problems in Milking Systems

University of Wisconsin, milk quality website: www.uwex.edu/milkquality

Standard Methods for the Examination of Dairy Products, 17th edition. H.M. Wehr and J.F. Frank, editors, American Public Health Association, 2004. Washington, DC.

American Association Bovine Practitioners (AABP), www.aabp.org

FDA, Center for Veterinary Medicine, www.fda.gov/animalveterinary/default.htm

American Veterinary Medical Association, www.AVMA.org

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19

Lameness in Dairy Cattle

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Abstract

The most common noninfectious causes of lameness affecting the bovine digit are ulcers, white line disease, and traumatic lesions of the sole, including thin sole toe ulcers (TSTUs) predisposed by thin soles due to excessive wear or overtrimming. Some of these conditions are predisposed by metabolic disorders including rumen acidosis and laminitis along with other physiological factors that affect the integrity of the suspensory apparatus of the third phalanx, particularly during the transition period. All are complicated by mechanical factors induced by life on hard flooring surfaces that contribute to lameness either by encouraging overgrowth and altered weight bearing, or by predisposing to traumatic lesions of the sole sometimes exacerbated by abrasive flooring conditions. The second group of disorders affecting the ruminant digit is the infectious disorders of the foot skin. These represent some of the most common and important causes of lameness in cattle; however, unlike the lesion associated with a sole ulcer or white line disease that specifically affects the claw, these diseases affect the "skin" of the interdigital space, heel bulbs, and interdigital cleft (on the back of the foot above the interdigital space). Although there are some differences in the way these conditions develop and the way they appear, they all have at least one thing in common: They are caused by infectious agents capable of inducing inflammation and lameness.

Introduction

Noninfectious Disorders of the Bovine Foot

Laminitis (Pododermatitis Aseptica Diffusa)

Laminitis, known by some as founder, is an important underlying cause of disorders affecting the digit in cattle. It is characterized by a disruption in blood flow to the corium that results in inflammation and damage to tissues that suspend the third phalanx within the claw horn capsule. Laminitis occurs as an acute, chronic, and subclinical form. The following is a brief synopsis of the various ways in which laminitis may present itself, along with a brief overview of the tissues involved and events that occur in the pathogenesis of this disease.

Acute Laminitis

The acute form of laminitis occurs sporadically; however, incidence seems to be highest for first lactation animals within the first 30 days of lactation. Clinical signs include stiffness, pain, and extreme reluctance to walk. Horses will stand with forefeet placed forward whereas cattle typically stand with their back arched and feet placed more beneath them in a so-called "camped under" posture as shown in Figure 19.1. Because of the pain caused by inflammation of the corium, most animals spend the majority of time lying down. Discomfort and pain can be exaggerated by forcing the affected animal

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Figure 19.1. First lactation heifer with acute laminitis exhibiting the typical "camped under" posture.

to rise. Redness, swelling, and tenderness above the coronary band and over the bulbs of the heel are sometimes noticeable. If the animal will permit, one may be able to feel increased heat through the walls of the hoof and over the coronet. Practical therapy would include treatment for pain. Unfortunately, there are few options in cattle beyond aspirin and movement of the animal to a soft surface such as grass pasture, dirt, or sand lot, a well-bedded stall, or other area free of concrete and gravel or stone. Nonresponsive cases should be culled or when particularly severe, for humane reasons euthanized.

Chronic Laminitis

Clinical signs associated with the chronic form of laminitis are generally mild and undetectable with the exception of noticeable hoof wall changes that occur over time. With chronic laminitis, claws widen, flatten, and develop characteristic horizontal ridges sometimes referred to as "hardship grooves." Lesions of the corium are similar to those described above for the acute form of laminitis; however, they occur more gradually, resulting in less obvious signs of discomfort.

Subclinical Laminitis

Subclinical laminitis is the more common form of this disease. As implied by its name, clinical signs of laminitis described previously are absent. Hence, it is sometimes referred to as a syndrome associated with a variety of lesions occurring secondary to sinking of the third phalanx and the production of hoof horn that is weaker and less resistant to physical stresses. Poor horn quality predisposes to mild to moderate structural abnormalities of the claw capsule. In addition, claw horn wear may be accelerated, contributing to an increased risk of solar injury and bruising, and a heightened potential for bacterial invasion of the hoof, particularly through the white line.

Lameness due to white line disease and/or ulcers of the toe, sole, and heel may increase in herds affected with laminitis. Therefore, whenever the incidence of claw disorders increases in a herd, it is important to establish the possibility of subclinical laminitis as an underlying cause. As with the acute and chronic forms of laminitis, first lactation animals within the first 30 days of lactation seem to be the most susceptible. There are several reasons for this which we describe in greater detail later in this chapter.

Lesions of the foot that are most characteristic of the subclinical laminitis condition would include (1) visible hemorrhages of the sole that may appear as bruises or pink staining of the solar horn or hemorrhages arranged in the form of striations; (2) solar horn that is particularly soft, yellowish, and/or waxy appearing and cuts easily with a hoof knife; (3) an increase in lameness where lesions observed are primarily ulcers and white line disease. Regular review of the cumulative lesions observed at trimming and during the treatment of lameness forms the basis for early recognition of possible problems with subclinical laminitis (Van Amstel & Shearer, 2006).

Anatomical/Histological Perspectives

The corium consists of four distinct regions: (1) solar corium, which produces the horn of the sole; (2) perioplic corium, which produces the horn immediately distal to the skin horn junction (analogous to the cuticle in humans) and also the horn of the heel; (3) laminar corium, which produces the horn of the white line and also contains the collagen fiber bundles that make up the suspensory apparatus of the third phalanx (P3); and finally, (4) coronary corium, which lies distal to the perioplic corium and proximal to the laminar corium region; it produces the horn of the wall.

Adjacent to the corium (moving toward the exterior or surface of the horn capsule) is the basement membrane and a series of epithelial cell layers that comprise the claw horn; these are the germinal or basal cell epithelium, stratum spinosum, stratum lucidum, and the outermost layer, the stratum corneum or horn layer. The germinal epithelium contains two types of cells: (1) keratinocytes; the most abundant cells that have the ability to produce and accumulate keratin within their interior and (2) basal cells that remain with the germinal layer. Keratin is a fibrous scleroprotein that imparts strength to the keratinocyte, giving it resistance to

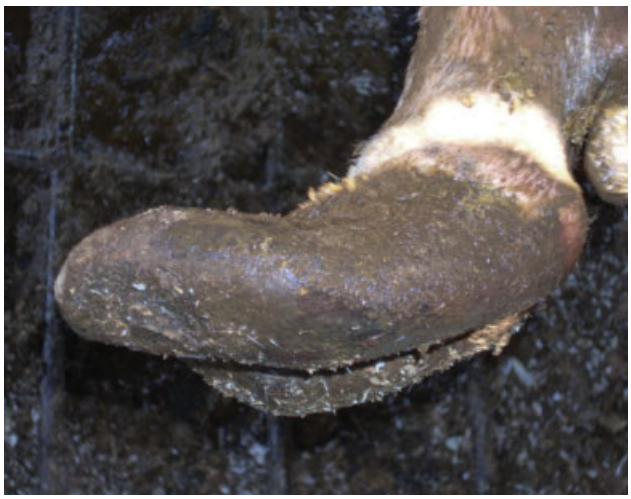

Figure 19.2. Foot of a cow with chronic laminitis showing the characteristic flaring and concavity typically observed in cows with this condition.

physical and mechanical forces (Budras et al., 1996). Between each of these cells is intercellular cementing substance, a lipoprotein that binds the keratinocytes together, like the mortar between bricks in a wall. Cells within the germinal epithelium and lower layers of the stratum spinosum are "living cells" by virtue of a steady flow of nutrients received from the corium by diffusion across the basement membrane. Since the natural progression and movement of keratinocytes is outward from the corium and away from their nutrient source, these cells are in the continual process of a slow death as they reach the upper layers of the stratum spinosum and stratum lucidum. The outermost layer is the stratum corneum, the layer where the keratinocytes have gone beyond the reach of nutrients, have died, and have become cornified or horn-like. Conditions such as laminitis that result in the disruption of blood flow to the corium not only affect the corium but also the keratinocytes within the epithelial layers destined to become claw horn. Flaring of the hoof wall (paddle-footed cows) and concavity of the dorsal wall of the claw are indicators of poor quality horn (decreased keratinization rates), and characteristic of laminitis, particularly in its chronic form, as shown in Figure 19.2.

The Pathogenesis of Laminitis

The pathogenesis of laminitis is associated with a disruption in the microcirculation of blood within the corium which leads to breakdown of the dermal–epidermal junction between the claw wall and the bone (otherwise known as the P3 within the claw). Rumen acidosis is considered to be a major predisposing cause of laminitis presumably mediating its destructive effects through various vasoactive substances (endotoxins, lactate, and possibly histamine) that are released into the blood stream in coincidence with the development of rumen acidosis. These vasoactive substances initiate a cascade of events in the vasculature of the corium, including a decrease in blood flow caused by the simultaneous dilatation of arterioles and constriction of venules that leads to endothelial cell damage and the extravasation of blood fluids into extravascular tissues of the corium. This is complicated still further by stagnation of blood within the microvascular system that leads to thrombosis, ischemia, hypoxia, and eventually arterio-venous shunting. The end result is inflammation accompanied by edema, hemorrhage, and necrosis of corium tissues. Functional disturbances follow including the activation of matrix metalloproteinases (MMPs) that degrade the collagen fiber bundles of the suspensory apparatus of the P3 (Lischer et al., 2002). These changes are exacerbated by the activation of epidermal growth and necrosis factors that contribute to structural alterations involving the basement membrane and capillary walls (Ekfalck et al., 1998; Ossent & Lischer, 1998).

These vascular effects also interrupt the differentiation and proliferation of keratinocytes within the germinal cell layer of the epithelium. This leads to reductions in the keratinization of horn cells in the stratum spinosum which decreases the structural rigidity and strength of claw horn (Mulling & Lischer, 2002). Poorly keratinized horn is weaker and is less resistant to mechanical, chemical, and possibly even microbial invasion (e.g., presumably increasing susceptibility to conditions such as heel erosion).

The Suspensory Apparatus of P3

The laminar corium (sensitive lamina) of the claw is the primary suspensory tissue for P3. Cows essentially "hang in their claws" by virtue of a series of laminar folds that are anchored on the abaxial, dorsal, and axial surface of P3, and extend outward to interdigitate with the lamelle of the wall (Ossent & Lischer, 1994; Blowey, 1996; Ossent and Lischer, 1998; Lischer & Ossent, 2002; Lischer et al., 2002). Beneath P3 are tissues which make up the underlying support structure for P3. This tissue is composed of loose connective tissue from the solar and perioplic corium, and caudally by the digital cushion (DC). The DC is an important support structure composed of loose connective tissue and varying amounts of adipose tissue. It has become the object of attention by several researchers in recent years as recent observation suggests that the size and type of fat within the DC may have important implications in the occurrence of lameness (Raber et al., 2004; Bicalho et al., 2009).

Inflammation leading to destruction of the dermal–epidermal junction results in weakening of the suspensory apparatus that predisposes to the downward displacement and rotation of the P3 (Ossent & Lischer, 1994, 1998). The result is compression of the corium and supporting tissues that lie between P3 and the sole which predisposes to the development of sole ulcers. In some cases, rotation of the apex of P3 is severe enough to cause dysfunction of the corium in this region and predispose to a toe ulcer. If, on the other hand, sinking of the P3 is such that the rear portion sinks furthest, compression at the heel–sole junction will result in the development of a sole or heel ulcer. Sole ulcers are one of the most common claw lesions in dairy cattle and constitute one of the most costly of lameness conditions. They are described in following sections.

Displacement of P3 by Alternate Mechanisms

While most have considered rumen acidosis to be the primary cause of laminitis, lameness researchers in recent time suggest that it is more complicated than previously believed. In fact, the claws of cows and particularly heifers are less resistant to compressive loading forces than previously thought and especially so during the peripartum period (Mulling & Lischer, 2002). The confinement of cows on hard surfaces is potentially one of the single most important predisposing causes of lameness in dairy cattle.

Activation of MMPs by "Hoofase"

Researchers from the United Kingdom studied the supportive capacity of the suspensory apparatus of P3 in first lactation heifers and age-matched maiden heifers during the peripartum period (Tarleton & Webster, 2002; Tarlton et al., 2002). They observed increased laxity, reduced rigidity, decreased load-bearing capacity, and a clear deterioration in the structural integrity of hooves in first lactation heifers (Webster, 2001, 2002). Furthermore, these changes appeared to be progressive over the period of 2 weeks prior to calving until 12 weeks postcalving. These hoof characteristics were not observed in age-matched maiden heifers. Workers suggested that these changes would permit sinking of P3 and thus predispose affected animals to compression of the corium and sole ulcers.

Biochemical explanations for these observations were explored, and in the process they dentified a unique ~52 kD gelatinolytic enzyme they termed as "hoofase" (Tarleton & Webster, 2002; Tarlton et al., 2002). This enzyme was isolated from all specimens derived from calving heifers; however, none was found in specimens from the maiden heifers. Researchers also sampled each of the study groups to determine if there was relationship between hoofase and the types and levels of metalloproteinases (MMP) isolated from the connective tissue samples. Interestingly, they observed the highest levels of hoofase in pregnant heifers approximately 2 weeks prior to calving. In addition, they found highly significant increases in the activated form of metalloproteinase-2 (MM-2), a very important metalloproteinase involved in the mediation of collagen remodeling in normal animals. On the other hand, levels of metalloproteinase-9 (MM-9), the enzyme most consistently associated with inflammation as related to rumen acidosis, was not found in significant quantities in either the first lactation or maiden heifers. This suggested that the classical form of rumen acidosis-induced laminitis was not a cause of the changes observed. There were marginal increases in "proMM-2" (a metalloproteinase normally responsible for physiological and pathological remodeling of connective tissues). They concluded that these results indicate that hoofase plays a very important role in the activation of MM-2 and weakening of the suspensory apparatus by a mechanism quite different than that related to rumen acidosis (Tarleton & Webster, 2002; Tarlton et al., 2002). Considering observations by these researchers that peak hoofase activity occurs approximately 2 weeks prior to calving, and that it continues well into the early postpartum period, one must conclude that hoofase may have a very important role in the cause of claw lesions.

Peripartum Hormonal Effects

Researchers from the United Kingdom have suggested yet another mechanism for weakening of the dermal–epidermal segment between the wall and P3. Their work suggests that weakening of the suspensory tissue may be the result of hormonal changes that normally occur around the time of calving. In particular, hormones such as estrogen and relaxin, responsible for relaxation of the pelvic musculature, tendons, and ligaments around the time of calving, are thought to have a similar effect on the suspensory tissue of P3 as well. Whereas this is likely a natural phenomenon around the time of calving, housing animals on soft surfaces during the transition period (4 weeks prior to calving through 4–8 weeks after calving) may be an important management procedure to reduce or alleviate the potential for permanent damage to these tissues. Researchers base this opinion on observations that fewer claw lesions occurred in heifers housed in straw yards compared with those housed in free stalls during the transition period. Researchers concluded that first lactation animals in particular would benefit from softer flooring surfaces

during the peripartum period (Tarleton & Webster, 2002; Tarlton et al., 2002).

German researchers suggest that sinking and rotation of P3 may be associated with as of yet unexplained structural alterations occurring on the surface of P3 where the suspensory tissues are anchored. It is clear that despite the preponderance of information linking laminitis to feeding conditions and rumen acidosis, softer flooring surfaces and cow comfort cannot be overlooked as requirements for animals during the transition period (Mulling & Lischer, 2002).

Ulcers of the Toe, Sole, and Heel (Pododermatitis circumscripta, Rusterholtz Ulcer/Sole Ulcer, Toe Ulcer, and Heel Ulcer)

Displacement of P3 results in compression of the solar and perioplic corium between P3 and the sole (Raven, 1989). Contusion and bruising of the corium at the toe, sole, and heel causes injury and dysfunction of the corium (Fig. 19.3). In cases where displacement of P3 involves severe rotation of its apex, a toe ulcer may develop. If, on the other hand, sinking of P3 is such that the rear portion sinks furthest, compression of the solar and perioplic corium of the heel will lead to development of a sole ulcer ("Rusterholtz ulcer") at the heel–sole junction (characterized by Toussaint Raven as the "typical site" most commonly associated with the development of sole ulcers; zone 4 on the Claw Zone Diagram in Fig. 19.4).

An ulcer is defined as a full-thickness defect or break in the epidermis that exposes the corium. One of the earliest indications of a developing sole ulcer is hemorrhage in the sole, particularly when it occurs at the heel–sole junction. If the animal exhibits pain when pressure is applied to this area, it offers good evidence that the ulcer is in the clinical stage. With additional time and trauma associated with weight bearing, this lesion will likely progress to a full-thickness horn defect or ulcer. In the preclinical or early stages of development, despite the size of some hemorrhages, pressure as might be applied with a hoof tester causes little or no discomfort. Treatment of these cases may be accomplished by lowering the heel on the affected claw so that it may have time with reduced weight bearing for rest and repair. If, on the other hand, one is able to elicit pain by putting gentle pressure over this area with a hoof tester, one should not only lower the heel on the affected claw, but also consider application of a foot block to the healthy claw to insure complete relief from weight bearing (Raven, 1989; Shearer & Amstel, 2002). When identified early, these cases will usually recover quite rapidly (within 3–4 weeks).

Mature ulcers are usually accompanied by lameness and even gentle pressure with a hoof tester over the ulcer site will elicit a positive pain response (Fig. 19.5a,b) Removal of superficial layers of horn may uncover an area of exposed corium that is extremely sensitive. Assuming minimal damage of the corium, these may be treated by thinning horn around the base of the ulcer and lowering this area relative to the weight-bearing surface of the healthy claw. It is also advisable to avoid leaving a crater or hole in the sole that will fill with organic matter. Instead, slope the sole axially toward the interdigital space. Recovery time for ulcers requires a minimum of 20–30 days, and based on studies by European workers, as much as 50–60 days in severe cases (Van Amstel et al., 2003a). The objective should be to

Figure 19.3. Foot with a sole ulcer as evidenced by a hemorrhage in the "typical site."

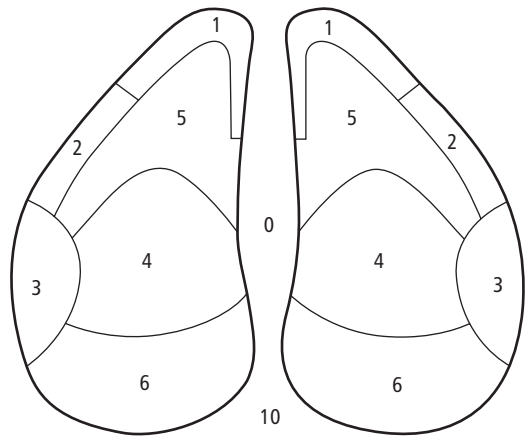

Figure 19.4. Claw Zone Diagram: (1) white line at the toe, (2) abaxial white line, (3) abaxial heel-wall junction, (4) sole–heel junction, (5) apex of the sole, and (6) heel.

Figure 19.5. Mature sole ulcers. (a) Sole ulcer soon after corrective trimming and application of a footblock. (b) Sole ulcer prior to application of corrective trimming procedures and a foot block.

provide relief from weight bearing on the affected claw for at least 1 month by means of a foot block, and an additional 20–30 days by corrective trimming to adjust load bearing between the two claws (Shearer & Amstel, 2001). It is important to remember that if there has been significant damage to the corium recovery may be extended. In some cows this may require that a new block be applied as soon as the first one is no longer functional due to wear.

For chronic ulcers where long-standing inflammation has resulted in granulation tissue formation, first, apply the corrective trimming procedures described above. Next, carefully remove the granulation tissue with a sharp hoof knife. Be careful not to damage adjacent normal tissues of the corium. Granulation tissue bleeds freely, and recurrence rates for ulcers with exposed granulation tissue are high (Van Amstel et al., 2003a).

To fully understand the pathogenesis of ulcers, one must recognize their multifactorial etiology. The metabolic factors responsible for sinking and rotation of P3 include rumen acidosis and laminitis, and also the effects of enzyme activity and hormonal changes that are most common during the transition period. The mechanical factors of greatest importance are those that contribute to unbalanced load bearing within and between claws. The work of Toussaint Raven demonstrates that weight does not distribute itself evenly, but more to the outer claw. This increased weight bearing leads to accelerated horn growth and overloading of the outer claw, the consequence of which increases weight load and pressure on the corium. The biomechanics of loading within the weight-bearing surface are also affected by toe length. When the toe is long, the sole in the region of the toe is always thicker. This creates a greater distribution of weight caudally toward the heel–sole junction and is therefore believed to be a contributor to the development of sole and heel ulcers. The purpose of maintenance or preventive hoof trimming procedures is to reestablish appropriate weight bearing within and between claws by eliminating abnormal overgrowth that leads to overloading of the claw (Raven, 1989; Shearer & Amstel, 2001).

Finally, size and type of fat within the DCs has become a source of interest in understanding the pathogenesis of sole ulcers as well (Lischer & Ossent, 2002; Lischer et al., 2002). The DC lies immediately above the loose connective tissue of the corium and beneath P3. It consists of three roughly parallel cylinders (axial, central, and abaxial) composed primarily of fat that serve as shock absorbers in the heel. Studies by Swiss researchers have found that the DC of heifers is smaller in size and contains more saturated fat, which reduces its cushioning value as compared with mature cows (Lischer & Ossent, 2002; Lischer et al., 2002; Raber et al., 2004). These characteristics of the DC in heifers may increase the vulnerability of young animals to claw diseases, particularly sole and heel ulcers. Furthermore, observation of the feet of animals suffering laminitis indicates that the sinking of P3 leads to damage of the DCs and replacement of the fat with firmer connective (even cartilaginous or cartilage-like) tissue. The combination of a harder, less flexible DC and compression of the corium caused by sinking of P3 results in greater damage to the corium in the heel and, consequently, a greater risk of sole and heel ulcers.

Effects of Body Condition on Claw Disorders

The impression of most people is that lame cows lose weight. This is logical since lameness causes pain and reduces their interest in walking or standing and,

therefore, the number of trips a cow might be willing to make to the feedbunk. However, a recent study suggests that rather than lame cows becoming thin, it may be that thin cows become lame. These researchers investigated the relationship between claw lesions (ulcers and white line disease) and thickness of the DC in 501 lactating Holstein cows. They found that the prevalence of sole ulcers and white line disease increased as thickness of the DC decreased. They also observed that DC thickness decreased steadily throughout lactation reaching nadir (i.e., its lowest point) at 120 days after calving. Body condition scores (BCS) of cows were positively associated with thickness of the DC, whereby an increase in BCS was associated with a corresponding increase in mean thickness of the DC (Bicalho et al., 2009).

Results of this study add further credence to the idea that claw lesions bear a close relationship to external factors, in particular confinement housing and hard flooring surfaces. Furthermore, it is tempting if not reasonable to theorize that the mobilization of fat in early lactation is a significant risk factor for lameness. The results of several studies are now beginning to suggest that when the shock-absorbing properties of the DC are compromised, the corium becomes vulnerable to mechanical injury. Knowing that cows mobilize fat from multiple body locations, it is reasonable to assume that they would likely mobilize fat from the DC as well. Researchers noted a decrease in thickness of the DC and also evidence of a change in the DC composition as BCS decreased (Bicalho et al., 2009).

The above study demonstrated that the highest prevalence of sole ulcers occurred near peak lactation (i.e., 60–100 days in milk); the point at which shrinking of the DC was approaching nadir. This is not unlike observations from other studies and also supports an association with a thinner, less functional DC. However, the rumen acidosis–laminitis complex, the effects of hoofase or activation of metalloproteinase activity, and/or the impact of peripartum hormonal changes can all be theorized as causes of these conditions in a similar time frame. Therefore, these observations do not preclude nor reduce the significance of other causative factors as mentioned earlier in this chapter. Rather, they highlight the complicated pathogenesis of lameness and its multifactorial causes.

White Line Disease

The white line is produced by the laminar corium. It is a three-part structure consisting of an outer, intermediate, and inner zone (Mulling, 2002). The outer and intermediate zones consist of laminar horn, whereas the inner zone (adjacent to the sole) is a heterogeneous combination of laminar horn and loosely arranged tubules. These structural features make it the softest, least resistant part of the claw capsule and subject to damage by mechanical shearing forces as well as penetration by bacteria and foreign bodies such as coarse dirt and gravel. The area of the white line most commonly affected is the abaxial heel-sole-wall junction of the lateral claw (zone 3 on the claw zone diagram and shown in Fig. 19.6). The white line in this region is naturally predisposed to greater mechanical impact and wear during locomotion since this area bears the impact of heel strike during the foot placement phase of the stride. As described above, overgrowth and overloading of the outer claw tends to exacerbate load bearing and may increase white line disease problems (Mulling, 2002).

Figure 19.6. White line disease at the abaxial heel-sole junction (zone 3).

Lesions within the white line normally begin as small cracks or spaces that become infiltrated with stones, dirt, or other types of organic matter. The entrapment of material within these spaces may be visualized as one or more dark lines within the white line running in an oblique direction. In other cases where separation is advanced and complicated by infection, the lesion may appear as a large area of loose necrotic horn within the white line. Abscess formation associated with white line disease creates severe lameness. These abscesses and the associated purulent material may accumulate in the subsolar region of the sole and heel, or in many cases they will migrate caudally toward the heel or upward beneath the wall. In the worst-case scenario, these may rupture, forming a sinus tract at the skin horn junction. On occasion, white line disease abscesses will penetrate the deeper structures of the foot including the distal

interphalangeal joint, deep flexor tendon and tendon sheath, and the navicular bursa and navicular bone. It is also important to note that white line disease is also considered to be predisposed by laminitis. As described earlier, disrupted blood flow to the corium, as occurs with laminitis, is likely to result in the production of dyskeratotic horn. This reduces the natural resistance of this structure predisposing to white line disease.

Treatment of these lesions requires paring away horn in an abaxial direction over the lesion at roughly a 45-degree angle (Raven, 1989; Shearer & Amstel, 2001). Paring of the tract leading to the abscess is required until all necrotic, loose, and undermined horn is removed and drainage (in the case of abscess formation) is accomplished. Always attempt to minimize collateral damage of normal healthy tissues. Always pull the knife away from the cow and slope the hoof wall adjacent to the abscessed area in an abaxial direction. This is an important step since removal of the wall adjacent to the abscess reduces weight bearing in this area and prevents extraneous material from being packed into the solar defect created by paring to establish drainage. This procedure may be painful, and in some cases, local anesthesia is required. Many animals will show immediate improvement, whereas others in which abscessation was more extensive and long-standing may take several days or weeks to improve. There is no need for systemic antibiotic therapy unless the infection extends to deeper tissues of the foot as evidenced by swelling and severe lameness. If swelling and severe lameness persists following antibiotic therapy, the cow should be reexamined for evidence of deep digital infection which may require surgery, culling, or euthanasia. Topical treatment and bandaging of claw lesions is unnecessary (see discussion on "Topical Therapy of Claw Lesions" later). Bandaging should be reserved for conditions where it is desirable to provide temporary protection of corium, such as when large areas of the corium have been exposed during corrective trimming procedures (White et al., 1981). See as shown in Figures 19.7a–d.

It should be remembered that abscesses occurring secondary to white line disease or ulcers are extremely

Figure 19.7. (a) Intravenous regional anesthesia using a 19-gauge butterfly catheter and 20 mL of 2% lidocaine and application of a foot block to the healthy claw. (b) Removal of all loose and necrotic horn associated with the white line lesion. (c) Corrective trimming complete with a minimum of additional damage. (d) A bandage applied with a nonirritating emollient (A&D ointment) on the raw tissue for the purposes of protecting the raw corium. Bandage to be removed or changed in 2–3 days.

painful. In most cases, pain can be alleviated through the application of a claw block to the healthy claw of the affected foot as described earlier for the treatment of sole ulcers. Elevation of the damaged claw suspends weight bearing, reduces discomfort, and promotes recovery.

Sole Abscess Associated with Traumatic Lesions of the Sole (Subsolar Abscess, Pododermatitis septica, Pododermatitis septica traumatica)

Beyond ulcers and white line disease, one of the more important causes of lameness is sole abscess. Sole abscesses are normally a secondary condition that may occur subsequent to ulcers, white line disease, or traumatic lesions of the sole such as a foreign body shown in Figure 19.8. For this reason, when referring to claw conditions that have abscessed, it is best to describe them as an abscessed sole ulcer, or a white line disease abscess, or a subsolar abscess due to trauma as by a foreign body.

There are many types of foreign bodies present in the cow's environment that are capable of causing traumatic lesions of the sole, for example, nails, stones, teeth, and wire and many others. Foreign bodies that breach the sole will usually create a septic lesion that after several days will develop into a subsolar abscess whereby pus is trapped between the solar corium and the sole. Treatment of this condition is as described above for white line disease lesions. Remove all loose and damaged horn around the solar lesion and apply a foot block to the healthy claw. In cases where necrosis of the corium and underlying tissue is more extensive, complications including septic osteitis of the third phalanx may develop.

Figure 19.8. A foreign body lodged in the sole as indicated by the hoof knife.

These are normally suspected when lesions do not heal properly and exhibit a persistent draining tract in a bed of granulation tissue on the surface of the sole.

It is important to note once again that many people refer to claw disorders collectively as sole abscesses. While it is true that ulcers and white line disease may abscess, the term "sole abscess" as a term to describe claw diseases in general is not very useful. The reason for this is that the underlying causes of each are different. Generally speaking, most people tend to examine the nutrition and feeding program first. While it is important to evaluate the feeding program for errors in feed bunk management and/or ration formulation, more often than not, the problem lies elsewhere. A meaningful recommendation to owners of herds on control and prevention of lameness disorders requires accurate information on the causes of lameness. An owner of a herd suffering problems with sole ulcers may need to evaluate cow comfort, nutrition, and management of cows around the time of transition. Herds suffering problems with white line disease with very few sole ulcers may need their owners to take a closer look at nutrition and feeding as well as flooring conditions. When traumatic lesions of the sole are the predominant problem, a thorough inspection of flooring conditions is more likely to offer appropriate ideas for corrective action (Shearer & Amstel, 2007).

Toe Lesions in Cattle

Toe lesions in cattle are common and often difficult to manage. One reason for this is the tendency for toe lesions to extend into the third phalanx. Once an osteitis is established, the lesion often becomes chronic and very difficult to treat, short of the complete removal of all involved tissues. Work to date indicates that there are at least eight conditions that may predispose to toe lesions. These include: toe ulcer (zone 5), white line disease (zones 1 and 2), thin soles and thin sole toe ulcer (TSTU) in zone 5 adjacent to the junction of zones 1 and 2, subsolar abscess associated with a traumatic sole lesion (foreign body), by a foreign body corkscrew claw (zones 1 and 2), wall cracks (especially horizontal wall cracks), trauma-related lesions affecting the tip or apex of the claw, and iatrogenic causes associated with overtrimming or improper trimming technique. Toe ulcers associated with laminitis are relatively rare. White line disease lesions in the toe are slightly more common and are sometimes associated with inappropriate trimming techniques (i.e., such as excessive removal of the axial wall). Laminitis may be a contributor to white line lesions in the toe (zones 1 and 2) as well, but the exact pathogenesis of these lesions is less clear. Corkscrew claw

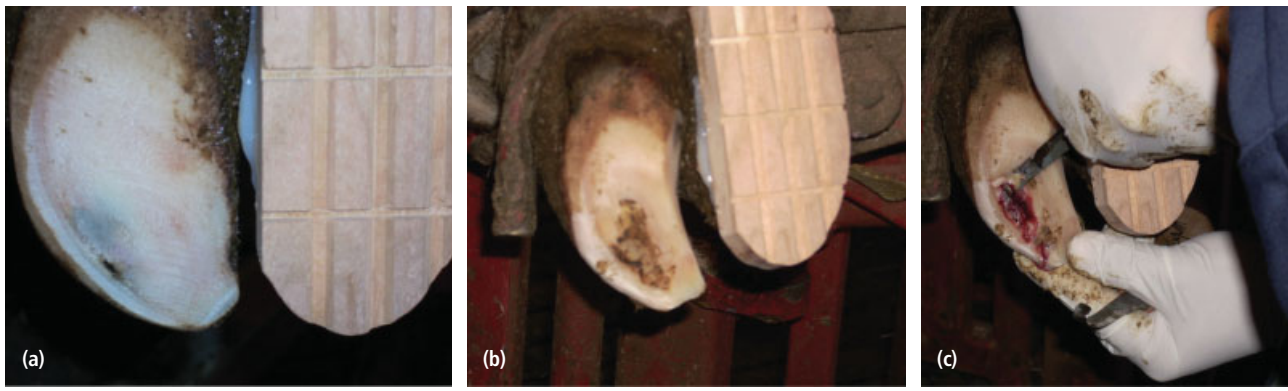

Figure 19.9. (a) Separation of the sole from the white line at the junctions of zones 1 and 2. (b) Removal of loose horn reveals a deeper lesion. (c) Additional corrective trimming reveals the full extent of the lesion.

is relatively common and frequently predisposes to toe lesions, resulting in abscess formation by a couple of different routes. Trauma-related lesions that result in toe abscess formation are more common in feedlot cattle or heifers where hyperexcitable animals are prone to traumatic injuries of the toe during processing, handling, or hauling. For dairy operations throughout the Southeast and more recently in other parts of the United States, one of the most common lesions is the TSTU. This lesion is a consequence of excessive thinning of the sole associated with accelerated claw horn wear, and on occasion overtrimming. These lesions are particularly prevalent, are difficult to treat, and predispose to lesions that frequently result in chronic lameness. Since ulcers, white line disease, and traumatic lesions of the sole have been discussed previously, the following discussion is limited to thin soles and TSTU, corkscrew claw, wall cracks, traumatic lesions of the claw apex, and iatrogenic or trimming-related toe lesions in cattle (Van Amstel & Shearer, 2008).

Thin Soles and TSTU

Thin-soled cows that develop lameness generally present with one of the following conditions: (1) thin soles that are flexible to finger pressure but have no ulceration and thus no exposure of the underlying corium, (2) thin soles that are flexible to finger pressure and have a break in the epidermis that exposes the underlying corium (i.e., TSTU), (3) thin soles that have progressed beyond the stage of ulceration to the formation of a subsolar abscess at the toe (toe abscess), and (4) thin soles that have progressed to the point of subsolar abscessation and osteitis of the third phalanx (Van Amstel & Shearer, 2008).

Normally the outer claw of the rear feet is most severely affected; however, in thin sole herds, the soles of all four feet usually show evidence of thinning. One will also note that heels are shallow, and soles give freely to finger pressure. Studies in the southeastern United States have determined that the most common lesion is a TSTU that develops secondary to thinning and separation of the sole from the white line in zone 5 adjacent to the junction of zones 1 and 2 (Van Amstel et al., 2003b; Van Amstel et al., 2004b; Shearer et al., 2006; Van Amstel & Shearer, 2008; Sanders et al., 2009). Based on the nature of the lesion (i.e., full thickness defect in the epithelium which exposes the corium) and its anatomical location, the authors have proposed that the lesion be termed a TSTU, that is, an ulcer caused by excessive thinning of the sole. The term "toe ulcer" has traditionally been used in relation to laminitis where downward displacement of the apex of the third phalanx causes pressure necrosis of the corium in the toe region with toe ulceration as a consequence. The term toe abscess is often applied to this lesion and often presented as a primary diagnosis. However, as indicated here, there are many causes of toe lesions. Therefore, before appropriate control measures can be implemented, one must determine the primary etiology as shown in Figure 19.9a–c.

Underlying Causes of Thin Soles

The purpose of the claw capsule is to protect the underlying soft tissues of the corium. A sole thickness of 1/4 inch (0.63 cm) is required to withstand the mechanical pressures imposed by the hard surfaces encountered in confinement and semiconfinement conditions. When conditions of overgrowth occur, the toe becomes longer (i.e., the dorsal ridge is more than 3 in. [7.6 cm] in length from approximately midway down in the periople to the tip of the toe) and the sole at the toe becomes thicker (greater than 1/4 in. or 0.63 cm). Weight bearing is disproportionately distributed toward the heel and heel–sole junction. In contrast, when the conditions of excessive wear occur, the toe is short (i.e., less than 3 in.

or 7.6 cm on the dorsal surface) and sole at the toe, thin (less than 1/4 in. or 0.63 cm; Raven, 1989; Shearer & Amstel, 2001).

Sole horn growth rates are affected by age, diet, and length of the daily photoperiod. Wear rates are influenced by the abrasiveness of flooring surfaces, cow comfort, horn quality, and claw horn moisture (Van Amstel et al., 2002; Van Amstel et al., 2004a). Therefore, the shape of the claw capsule is a product of growth and wear. In housing systems where the rate of sole horn wear exceeds the rate of growth, excessive thinning of the sole is likely to occur. Previous work has demonstrated that claw horn hardness is influenced by nutrition, contact with manure slurry, and moisture content of claw horn. In dairy environments during the summer months, claw horn is continually exposed to high moisture conditions particularly during the hot and humid summer months. Heat stress abatement procedures require that cows have access to sprinklers and fans, misters, or high-pressure fogging systems. Claw horn moisture content is also affected by manure management systems based on flushing of fresh or recycled water to clean floors in barns, holding areas, and travel lanes. Wear rates are also affected by the spatial layout of facilities which may require cows to walk long distances to and from barns and milking areas (Shearer & Amstel, 2007; Sanders et al., 2009). In some facilities, wear rates are further exacerbated by abrasive flooring conditions that include sharp turns and sloped walkways. Excessive sole horn wear is especially common in new installations where freshly hardened concrete creates a particularly abrasive surface as a consequence of the presence of surface aggregate which naturally forms on the flooring surface as the concrete cures. This observation has become so commonplace as to have its own name "New Concrete Disease" (Barnes, 1989; Cermak, 1998).

The occurrence of thin soles is also influenced by conditions contributing to poor cow comfort such as overcrowding and reduced stall use due to improper stall design and insufficient bedding. Issues of dominance also affect stall use. When stall numbers are equivalent or less than the total number of cows in the barn, timid animals such as heifers may have less opportunity to rest. A common recommendation is that dairymen provide at least 10% more stalls than cows to permit greater choice and encourage lying time, especially around the time of transition. Generally speaking, stall design should accommodate the following resting behaviors: (1) ability for the cow to stretch front legs forward; (2) ability for the animal to lie on its side with sufficient space for the head and neck; (3) ability for the cow to rest its head on its side; and (4) sufficient room for the cow to rest its legs, udder, and tail on the free stall platform and have a clean, dry, and soft bed. Some U.S. recommendations for Holstein cattle include construction of a free stall 8 ft (2.5 m) long (7 ft 6 in. [2.28 m]) for two facing rows) and 4 ft (1.25 m) wide with a brisket board 15 in. (38 cm) high and located 5 ft. 8 in. (1.72 m) from the stall curb (Cook, 2003, 2006). Even longer free stalls up to 9 ft 8 in. (2.94 m) are currently recommended by some particularly when the stall faces a wall.

The possibility of overtrimming should always be ruled out whenever thin soles are identified as a herd problem. Different trimming methods can result in significant differences in sole thickness. One study found that the method commonly referred to as the Dutch method of claw trimming resulted in fewer thin soles compared to another method, which used the white line as a guide to estimate sole thickness. The Dutch method uses toe length as a guide to estimate sole thickness (Raven, 1989; Shearer & Amstel, 2001). For the average adult Holstein cow, a toe length of 3 in. (7.6 cm) corresponds to a sole thickness of 0.25 in. (0.63 cm), which under normal circumstances of growth and wear, provides enough sole horn to protect the corium (the quick underlying the sole horn).

Clinical Observations

Treatment and Management of Thin-Soled Cows

Treatment of thin-soled cows requires careful evaluation of the sole of all claws. The first objective in treatment is to determine if the more sound of the two claws being evaluated on each foot can support the weight on that limb if fitted with a foot block to relieve weight bearing on the thin-soled claw. If the answer is yes, then a block is fitted to the most sound of the two claws. On the other hand, if it is determined that neither claw can support the weight of the respective limb, then neither claw should be fitted with a block, and the animal should be housed in an area free of concrete or other hard and potentially abrasive surface. Special needs areas that are close to milking facilities and designed with soft flooring surfaces are a good housing option for affected animals. An alternative to housing in special needs areas is a grassy area or dry lot close to the parlor that limits the distance cows must walk on hard or abrasive surfaces during the period of time desired for recuperation and horn growth (Shearer & Amstel, 2001; Van Amstel et al., 2003b; Sanders et al., 2009).

In cases where the condition has progressed to the point of ulceration, subsolar abscess formation, or osteitis of the third phalanx, additional corrective trimming and debridement procedures are necessary. All loose and undermined claw horn associated with the lesion should

be carefully removed without causing damage to adjacent tissues of the corium. Sole horn separation from the corium can become quite extensive in cases where the solar corium has become traumatized and infected with the formation of a subsolar abscess. Apart from formation of a subsolar abscess, the infection may spread into the white line resulting in necrosis of the white line with separation from the wall. The overlying separated portion of the wall should be removed to the point where reattachment between the wall and healthy corium is evident.

Management of individual thin-soled cows not only depends upon severity of the condition but also stage of lactation, pregnancy status, and age. Culling should be considered in cases of nonpregnant older cows, with a prolonged lactation, and low milk yield. Cows that are thin-soled on all claws with one or more toe ulcers and abscesses in the sole horn and severely lame irrespective of age, pregnancy, or lactation status are considered to have a poor prognosis, and culling or euthanasia is recommended based on economic and welfare considerations.

One approach to alleviating problems presented by abrasive flooring surfaces is the strategic application of rubber belting or mats to holding areas, walkways, or along feed mangers (Shearer & Amstel, 2007). Rubber cushions the foot and reduces the abrasive properties of flooring surfaces, but some forms such as conveyor belting can be slippery and increase injuries from falling. Canadian researchers observed that Animat (Animat, Saint-Elie d'Orford, Quebec City, Canada), a revulcanized form of rubber flooring with burls to improve traction, reduced slipping and increased the cow's confidence in her flooring surface (Rushen & de Passille, 2006). These researchers concluded that traction is dependent upon the degree of texture or roughness of the rubber surface and its compressibility features. Finally, a Midwestern study observed that rubber resulted in a decrease in the incidence of lameness from 67% to 33%. In addition, lameness due to thin soles in first lactation animals was decreased from 22% to 4% following the installation of rubber (Van Amstel et al., 2006).

Corkscrew Claw (Otherwise Known as Screw Claw)

Corkscrew claw is most commonly observed in the lateral claw of the rear leg in cattle. It is reported to be a heritable condition; however, other factors such as age, previous claw disease, and housing conditions are likely to influence its occurrence. It is characterized by rotation of the toe that displaces the sole, axial wall, and white line in an axial direction. There are a couple of important abnormalities present in the heritable form of this condition: a misalignment of the second and third phalanges and a long and narrow third phalanx that has an abaxial to axial curve. This curving of the claw and its internal structures results in weight bearing on the mid to caudal portion of the abaxial wall. The corkscrew claw is also normally larger and bears the majority of weight in the foot. As a consequence, the inner claw frequently atrophies from the lack of weight bearing. These abnormalities contribute to a greater potential for white line lesions in the abaxial region of the toe (junction of zones 1 and 2) since the corium is likely to be in an abnormally close proximity to the weight-bearing surface in this region. In addition, white line horn in this region is frequently weaker and is more easily compromised by external factors. Trimming generally requires great care as it is quite easy to expose the corium in this region during the trimming process. Overgrowth of the corkscrew claw is common and often predisposes to the development of sole ulcers as a consequence of elevated weight bearing.

Toe lesions in corkscrew claws develop in two ways: (1) white line separation in zones 1 and 2, and (2) as the inner wall twists and repositions itself dorsally, it also becomes folded over on itself, trapping organic matter within the fold (see Fig. 19.10a,b). This is a near-perfect environment for anerobic bacteria that eventually cause further necrosis and abscess formation that ultimately exhibits itself as a toe abscess. Most toe lesions in cattle with corkscrew claws occur by one of these ways. Careful examination of the lesion and the presence of corkscrew claw helps one discern the possibilities of this condition as a predisposing cause of toe abscesses. The only way to avoid such problems is trimming of the corkscrew claw at 3- to 4-month intervals to prevent extreme overgrowth, overloading, and thus sole ulcers and conditions that may lead to toe lesions.

An acquired form of this condition is commonly seen in dairy and beef cattle that feed from a manger. The acquired form of corkscrew claw affects the inner claw of the front foot and is believed to be associated with the abnormal displacement of weight that occurs in front claws of cows feeding a feed bunk (Raven, 1989). When cows are feeding at a manger, they are required to stand with their front feet in a side-by-side posture. As the cow reaches for feed, an abnormal stress and load bearing on front claws occurs that causes the medial claw to become corkscrewed. By comparison, cows at pasture normally graze with their front feet in a straddled posture. This posture balances weight bearing more normally between claws, thus preventing abnormal weight distribution and corkscrew claw development. Keeping feed pushed up so

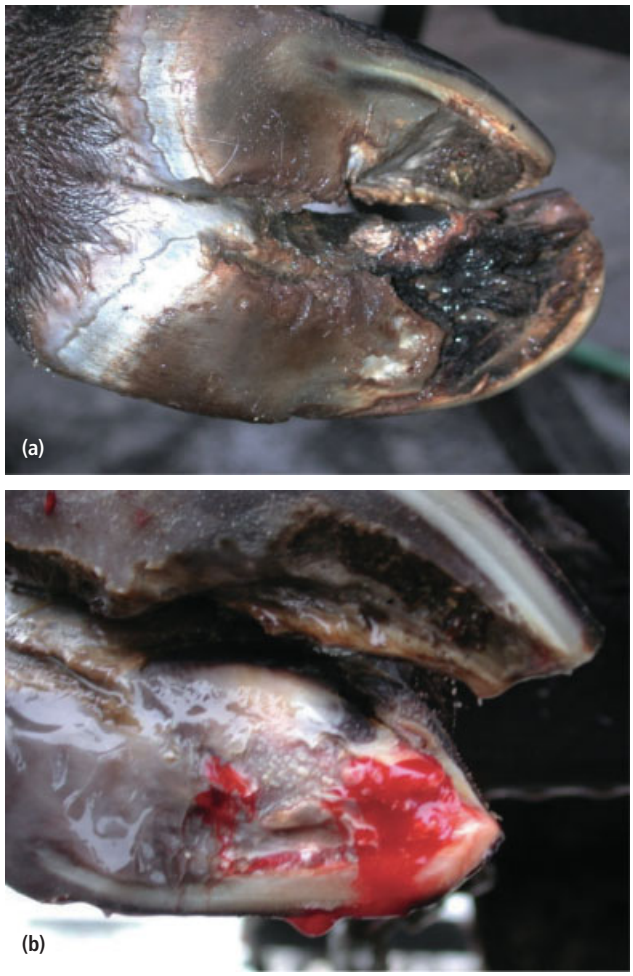

Figure 19.10. (a) Corkscrew claw with necrotic horn in the toe region. (b) Toe abscess following corrective trimming. Lesion began as a toe lesion on the axio-dorsal aspect of the corkscrew claw.

that cows do not have to reach helps avoid difficulties with this problem.

Wall Cracks in Cattle

Cracks or fissures in the hoof wall are common in cattle. Those which run in a vertical direction (from the coronet to the weight-bearing surface) are referred to as vertical wall cracks or sand cracks. Incidence rates as high as 64% have been reported in beef cattle, compared with less than 1% in dairy cattle. The percent of cows that may become lame with vertical wall cracks is generally low, but when lameness does occur, it may be difficult to treat or manage. For the foregoing discussion, we focus our attention on horizontal wall cracks.

Cracks or fissures that run in a horizontal direction (i.e., parallel to the coronet) are referred to as horizontal wall cracks. These are common in both beef and dairy cattle, and when severe, may result in profound lameness. The causes of horizontal wall cracks are better understood than those associated with vertical wall cracks. In some cases, they simply signal a "physiological change" that has resulted in a mild to moderate interruption of horn growth and formation in the basal cell layer of the coronary corium. In others, they are representative of conditions (often related to disease disorders) that have led to significant "physiological stress" and severe interruption of horn formation by the coronary corium. These severe disruptions in horn formation are exhibited as very distinct ridges and grooves that run in a horizontal direction on the hoof wall. They are often referred to as "hardship grooves" or "stress lines." In the most extreme cases where the fissure is sufficiently deep to result in a full thickness defect of the wall, the lesion is often referred to as a "thimble." On occasion, the segment of the wall closest to the weight-bearing surface becomes moveable as it nears the weight-bearing surface. When this occurs, it becomes extremely painful as it pinches and damages the underlying sensitive tissues.

Treatment of horizontal wall cracks is generally unnecessary; however, when pinching of the corium occurs, secondary to flexing of a portion of the wall, corrective procedures may be required. The objective is to stabilize the lose sections of the wall by removal of the loose portions. Application of a foot block on the opposite claw, assuming it is more stabile and will support a block, often provides relief.

Trauma-Related Lesions of the Toe

Cattle working facilities, rough or careless handling, certain types of flooring conditions, and hyperexcitability may contribute to an increased risk of trauma-related lesions of the toe. These are normally a little more common in feedlot cattle or younger animals that may be less accustomed to human contact and handling. Fractures of the claw capsule, and on occasion fractures involving P3, may lead to very severe lameness and complications such as the formation of a sequestrum. A sequestrum occurs most commonly when injury results in a fracture of the P3 bone with subsequent loss of blood supply to the portion of bone that becomes displaced as a result. Without a blood supply the tissue (in this case—bone) dies and becomes a sequestum. The body will naturally attempt to eliminate this dead bone material. It is not uncommon to find a loose necrotic piece of bone in chronic toe lesions. In many cases, removal of this necrotic bone will permit complete healing.

Iatrogenic-Overtrimming and Improper Trimming Technique

Until recent time, foot trimming techniques throughout North America were learned largely through experience or by working as an apprentice with an experienced person. In most cases, the trimming techniques applied to cattle were similar to those used on horses. However, as we have learned more about the anatomy and physiology of the bovine foot, our approach to trimming has changed. Toussaint Raven, with his book *Cattle Footcare and Claw Trimming*, is credited with introducing the greatest advancements in foot trimming technique in modern time. Properly applied, his functional claw trimming procedures prevent overtrimming of the foot, balance weight bearing within and between the claws of each foot, and provide the foot with stable weight-bearing surfaces on each claw (Raven, 1989).

One of the most common trimming errors is overtrimming. Different trimming methods can result in significant differences in sole thickness. For example, one study found that the trimming method described by Toussaint Raven (also referred to as the Dutch method) resulted in fewer overtrimmed feet as compared to another popular method. The Dutch method uses length of the dorsal wall as a guide to estimate sole thickness. For the average adult Holstein cow, a toe length of 3 in. (7.5 cm) corresponds to a sole thickness of ~0.25 in. (~0.63 cm), which under normal circumstances of growth and wear provides enough sole horn to protect the solar corium. However, trimming the sole to a thickness of 1/8 inch (~0.3–4 cm) or less creates conditions whereby the sole may not be to protect the underlying solar corium in an animal housed on a hard flooring surface. As described earlier, overtrimming typically leads to lesions in zone 5 characterized by separation of the sole adjacent to the white line in zones 1 and 2 (see section under thin soles).

There are several improper trimming techniques that may result in toe lesions: trimming the toe too short, excessive removal of axial wall and white line, and excessive removal of wall horn on the apex of the claw, and others. Many of these techniques create lesions by direct exposure of the corium or by causing weakness of the corresponding portion of the claw horn capsule affected (Shearer & van Amstel, 2001).

Finally, as keratinocytes migrate outward from the basal cell layer of the epithelium, they incorporate keratin within their cellular structure. The most mature horn cells and those with the greatest degree of kertinization are those within the stratum corneum layer. This corresponds to the most external layer or horn that has reached the surface of the claw capsule. Trimming removes the most mature and therefore the hardest horn layers of the claw horn capsule. Horn that remains is less mature and is thus softer (i.e., wears more rapidly). While regular trimming that corrects claw horn overgrowth and altered weight bearing is a useful adjunct to foot and leg health, trimming schedules that are too aggressive or frequent, coupled with flooring conditions that contribute greater-than-average wear rates, increase the potential for thin sole problems. Trimming schedules must be developed on a farm-by-farm basis in consideration of claw horn wear and growth characteristics unique to each operation.

Topical Therapy of Claw Lesions

Claw lesions are very painful conditions. Their appearance causes one to conclude that surely some form of topical treatment and a bandage would be an essential part of therapy. In reality, it is quite likely that treatment beyond corrective trimming and a foot block is counterproductive. These are in fact the principles of corrective trimming as described by Toussaint Raven, which include the removal of all loose and damaged or necrotic claw horn and relief from weight bearing.

Considering the pathogenesis of these lesions, aggressive treatment procedures and bandaging does not make sense. Sole ulcers, for example, are lesions that develop as a consequence of the sinking of the P3 exacerbated by claw horn overgrowth and overloading, particularly on the lateral claw. After a period of time with continued trauma to these tissues, horn formation in this area (the typical site) is interrupted. This coincides with the start of the formation of a sole ulcer. Eventually, the ulcer becomes sufficiently inflamed to cause pain and lameness which prompts our evaluation and discovery of the lesion during the course of trimming. The point is, *ulcers are not caused by infectious organisms; they are caused by conditions (such as laminitis) that predispose to the sinking of P3 and physical trauma to the corium complicated by excessive weight bearing*. Considering the fact that these lesions are not infectious in origin, there seems to be little logic for the use of use topical antibiotics in treatment. Contamination of the lesion will occur subsequent to corrective trimming regardless of the presence of treatment and/or a bandage. Since the organisms that cause abscesses in claws are anaerobic, the more important objective is the removal of loose and undermined horn that might create anaerobic conditions in the microenvironment of claw lesions. Aerobic conditions reduce the potential for abscess development in claw lesions.

Another temptation for some is to encourage bleeding of the corium tissues. In fact, excessive hemorrhage is simply a signal that one is damaging healthy tissues.

Although a small of hemorrhage is likely to occur in the process of corrective trimming, excessive bleeding is never desirable. Necrotic or dead tissue does not bleed, and there is no sensation because nerves and nerve supply to these tissues is dead. Trimming of claw lesions should cease when pain and hemorrhage are severe. The corium is the only tissue in the cow's body capable of producing claw horn. Every attempt possible should be made to avoid excess damage of these unique tissues.

The same comments apply to the cauterization of corium tissues with hot irons to control bleeding, or the direct application of caustic treatment materials on open lesions with exposed corium for treatment purposes. Such treatments have the potential to result in further damage to the corium that only increases pain and the time necessary for recovery. Even topical antibiotics that are not pH balanced or specifically designed for use on open lesions may cause excess irritation. These are likely of questionable value in the treatment of claw lesions. Toussaint Raven warns against parading cows with claw lesions through footbaths for similar reasons.

When topical treatment under a wrap is necessary, readers are encouraged to read label directions on guidance for such applications. Many topicals are not intended for use under a bandage or wrap. When topical treatment is deemed to be necessary, one should be careful to utilize only those medications that are not likely do harm to sensitive corium tissues. In summary, when considering treatment of claw lesions, probably the best rule of thumb is: *Do not do anything to a cow's foot that you would not do to yours.*

Infectious Disorders of the foot skin

Digital Dermatitis (DD) (Hairy Heel Warts)

Although DD was first reported in the United States around 1974 (Lindley, 1974), the disease was not a widespread problem until the early 1990s. The precise cause remains to be determined, but most studies to date indicate that the organisms observed in most lesions are bacterial spirochetes belonging to the genus *Treponema* sp.

Clinical Signs

The lesions of DD typically occur on the plantar aspect of the rear foot on the skin adjacent to the interdigital cleft, or at the skin–horn junction of the heel bulbs. On occasion, lesions may be found adjacent to the dew claws or bordering the dorsal interdigital cleft (particularly on front feet). Most lesions are circular or oval with clearly demarcated borders. Hypertrophied hairs surround the lesion borders and should be distinguished from filiform

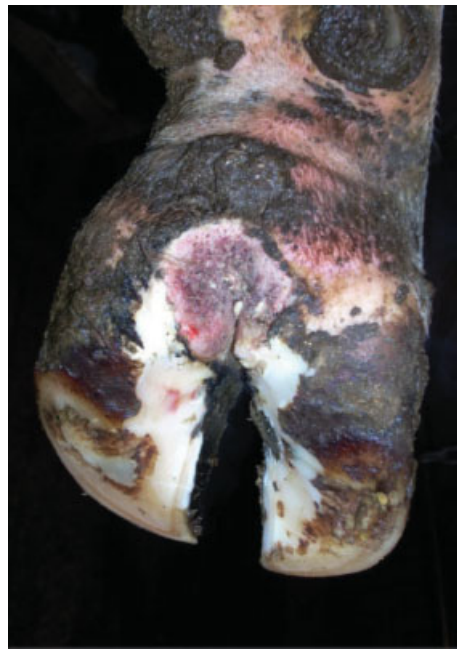

Figure 19.11. Digital dermatitis lesion in the plantar interdigital cleft.

papillae which often extend from the surface of chronic lesions. Chronic lesions without filiform papillae are generally thickened and have a granular surface. Histologically, lesions demonstrate a range of ulcerative and proliferative changes including ulceration of the dermal papillae, epidermal hyperplasia with parakeratosis and hyperkeratosis, and inflamation along with the presence of numerous spirochetes invading the stratum spinosum and dermal papillae (Read & Walker, 1998a,b).

Even a mild disturbance of the inflamed tissue tends to result in extreme discomfort and mild to moderate bleeding. Therefore, cows will alter their posture and/or gait to avoid direct contact between lesions and the floor or other objects. These pain avoidance adaptations also lead to abnormal wear of the weight bearing surface of affected claws. Lesions associated with the plantar interdigital cleft usually cause the cow to shift weight bearing toward the toe. This results in increased wear at the toe, decreased wear in the heel, and an overall reduction in the weight-bearing surface of the affected claw as shown in Figure 19.11

Epidemiology

The prevalence of DD in herds is quite variable and is usually underestimated by herd owners (Argaez-Rodriguez et al., 1997). Rates of 20% to more than 50% have been reported (Shearer & Elliott, 1998; Shearer et al., 1998). Despite the severe pain that animals seem

to experience when lesions are disturbed, lameness associated with this disease is inconsistent and is often lower than might be expected (Shearer & Elliott, 1998). It appears that pain resulting in lameness is often due to an extension of the lesion to the horny structures of the claw.

The housing, environment, and management conditions most consistently identified as predisposing causes of DD include large herd size, wet and muddy corrals, and the purchase of replacement animals. Other risk factors cited in a national U.S. study included use of a footbath, housing on grooved concrete, use of a trimmer who trimmed feet at other farms, and failure to clean and sanitize equipment between uses on cows (Wells et al., 1997). Although the latter study suggested important epidemiologic relationships, it did not distinguish between cause and effect. In other words, considering the relationship of footbaths and DD as cited in this study, analysis of the data did not establish that DD was caused by footbaths or vice versa. One would have to conclude, however, that housing and environmental hygiene are important factors in control of this disease. Furthermore, based on the above studies, the importance of hygiene could be extended to those who provide foot care services (veterinarians and/or trimmers) on dairy farms.

The highest incidence of DD is usually observed in early lactation. In some herds this is due to extremely high rates of DD in prefresh homegrown or off-site raised heifers. Herds that purchase replacements often fail to request DD-free animals or properly inspect purchased animals for the presence of DD lesions before introducing them into their herds. The transition from a nonlactating to a lactating state represents one of the more stressful periods in a cow's life. They must adapt to the physiological change associated with the initiation of lactation, adjust to changes in housing and feeding conditions, and successfully respond to issues of dominance by herd mates. It has been suggested that one of the potential causes of a higher incidence of DD in the early postpartum period may be due to periparturient immune suppression (Laven, 1999).

Possible reservoirs and mode of transmission of DD are largely unknown but assumed to be clinically and subclinically infected cows and fomites. The plantar interdigital cleft provides an excellent environment for the organisms and may be a significant reservoir. Attempts to reproduce the disease under controlled conditions has proven difficult but has been accomplished in calves. Experimental transmission was achieved by the placement of scrapings from DD lesions under a wrap designed to create an oxygen-depleted and moist microenvironment in the intended anatomical site. Typical lesions were observed after a period of several weeks.

Effects of DD on Performance

Few studies have attempted to assess the effects of DD on performance. A U.S. study found that cows affected with DD produced less milk (153.3 kg) than healthy cows; however, the difference was not significant (Hernandez et al., 2002). An earlier study conducted on a 600-cow dairy in Mexico had similar results. Cows affected with DD produced 121.6 kg less milk than their unaffected herd mates (Argaez-Rodriguez et al., 1997). But, as in the previous study, this difference was not significant. There were, however, significant effects on reproductive performance. For cows affected with DD, the calving to conception interval was increased from 93 to 113 days. Average days open were increased by approximately 14 days as compared with noninfected herd mates.

Treatment and Control Strategies

Past approaches to therapy include: (1) surgical excision, (2) footbaths (3) topical treatment with various disinfectants, and antibiotic solutions, (4) cryosurgery, and electrocautery, (5) topical treatment under a bandage, and (6) systemic antibiotic therapy. With the possible exception of cryosurgery and electrocautery, most of these treatments have a place in the management of this condition. However, they may not be practical in some situations.

Treatment strategies have been reviewed previously (Shearer & Elliott, 1998; Shearer et al., 1998). Topical spray-on treatment with antibiotic and some nonantibiotic preparations have been shown to be effective when used in a scheme of consistent daily treatment for a period of 8–10 days over a 2-week period. The major disadvantage to topical treatment is that lesions occurring in the interdigital space are missed. Topical antibiotic treatment under a bandage is particularly effective with most cows showing remarkable improvement within 24–48 h. Properly applied, this approach to treatment also has the potential advantage of reaching lesions affecting the interdigital skin. Footbaths containing various compounds including 3%–5% formalin, 5%–10% copper sulfate, 20% zinc sulfate, oxytetracycline 1–4 g/L, lincomycin 1–4 g/L, or lincomycin/spectinomycin 1–4 g/L have been recommended. Results vary widely.

Response to topical antibiotic treatment (topical spray or bandage) is also influenced by the anatomic location of lesions (Hernandez & Shearer, 2000). A Florida study

demonstrated that lesions occurring on the plantar interdigital cleft were less likely to respond compared with lesions occurring on the heel bulbs or dewclaws. Limited evidence also suggests that response to therapy may be influenced by lesion maturity and possibly antibiotic resistance patterns of etiologic agents. These factors should be considered in evaluating treatment responses as well as the development of new treatment strategies.

Interdigital dermatitis (ID) (Slurry Heel)

ID is an acute or sometimes chronic inflamation of the interdigital skin, extending to the dermis. It is extremely common in dairy cattle in free-stall housing conditions or other situations where the feet of cows are continuously exposed to wet manure slurry or muddy corral conditions (Raven, 1989; Somers et al., 2005). The disease is believed to be caused by a mixture of bacteria: *Fusobacterium necrophorum*, bacterial spirochetes, and possibly *Dichelobacter nodosus*. In the early stages, ID is characterized by superficial erosion of the interdigital skin that some are able to recognize by its distinctive foul odor. The interdigital lesion is usually painful to the touch and is followed by extension of the infection to the heel horn resulting in heel erosion, the most readily visible feature of this disease. Early on, the eroded heel horn develops a pitted appearance. As the disease progresses, the roughened pitted heel horn may be replaced by fissures which may be sufficient to result in severe undermining of heel and solar horn. Coincident with this heel erosion is an acceleration of hoof horn formation. Excessive hoof formation leads to overgrowth and overloading of the affected claws.

It is these effects of ID that are believed to make it an important predisposing cause of claw disease problems, particularly sole ulcers in dairy cattle in confined conditions. Effects of ID on the interdigital skin are similar. Chronic inflamation causes the interdigital skin to thicken, eventually resulting in the formation of an interdigital fibroma. The clinical diagnosis of ID is based on the presence of a thickened interdigital skin, pungent characteristic odor, pain to the touch, and the concurrent presence of heel horn erosion.

Foot Rot (Interdigital Phlegmon) and Super Footrot

Foot rot is an infectious disease of the interdigital skin characterized by the presence of an interdigital lesion, swelling, and moderate to severe lameness. Fever ranging from 103–105°F (occasionally higher) is a consistent finding during the acute stages. Although evidence is inconclusive, most believe that foot rot develops following injury or abrasion of the interdigital skin. This interdigital injury is secondarily infected by *Fusobacterium necrophorum* alone, or in combination with *Bacteriodes melaninogenicus*, organisms that encourage progression to a more severe and necrotic-type of lesion. Failure to institute treatment early in the course of the disease may lead to complications involving surrounding soft tissues (tendons, tendon sheaths, joint capsules, and bone), ultimately resulting in deep digital sepsis. At this stage, response to medical therapy is quite often unrewarding, thus limiting one's options to either surgery, or possibly euthanasia, in particularly severe cases.

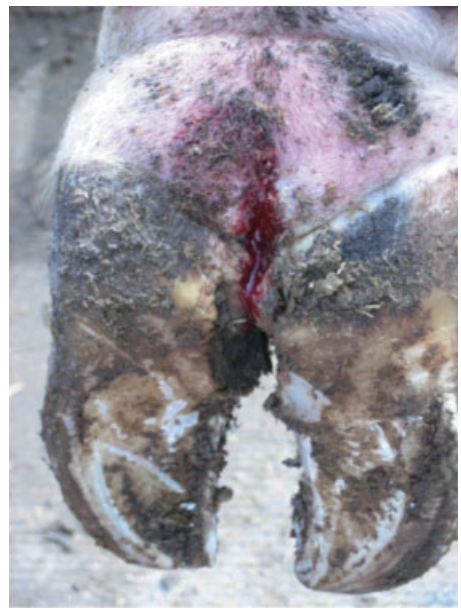

Figure 19.12. A case of foot rot with hemorrhage of the interdigital lesion and generalized swelling.

A study conducted at the University of Florida found that foot rot was associated with a 10% decrease in milk production in affected cows (Hernandez et al., 2002). This was greater than the milk loss observed for cows with claw disorders or DD. Most cows developed the disease in early lactation as they were approaching peak milk yields, suggesting that the occurrence of this disease in early lactation may inhibit a cow's ability to achieve peak milk yields. Foot rot is particularly important not only due to the pain and debility that it causes when animals are affected, but also because deep digital sepsis (infection of the distal inter-phalangeal joint) is a possible secondary complication as shown in Figure 19.12

In recent years, clinicians from the United Kingdom and the United States have observed a more extreme form of this disease referred to as "Super Footrot" (David, 1993). It is characterized by acute onset of lameness and

swelling of the foot that progresses rapidly to an ascending cellulitis. The interdigital lesion associated with "Super Footrot" is especially severe and successful treatment is particularly challenging.

Treatment of Foot Rot and Super Footrot

Foot rot is responsive to most antibiotics in common use for cattle. In fact, dose and duration of treatment are likely more important than antibiotic selection. The key to achievement of a successful therapeutic outcome is dependent upon prompt recognition and early implementation of treatment procedures. Systemic therapy plus topical treatment of the interdigital lesion have long been the preferred methods of treatment. In uncomplicated cases, improvement is noticeable within 24–48 h with good recovery attainable in 3–4 days from the onset of treatment. Treatments of choice are Naxcel® (Ceftiofur Sodium; Pfizer Animal Health, New York, NY), Penicillin, Albon® (Sulfadimethoxine; Pfizer Animal Health), and tetracyclines (extra-label in dairy cattle). Some prefer to simultaneously treat the interdigital lesion as well. Various antiseptic-type products may be used as topical treatments. Bandaging of the foot is unnecessary. Regardless, the secret to success is early detection of the disease.

Strains of bacteria responsible for Super Footrot may be particularly resistant to most antibiotics. Culture and susceptibility testing may be useful, but the rapid progression of the disease may preclude this as a viable option in existing cases.

The Capture of Lameness Data for Analysis and Interpretation of Foot Health

The greatest deficiency in the recording of health information has been in the area of foot care. Despite the fact that it is by some calculations the single most costly disease of dairy cattle, systems for the capture of information on lameness conditions remains poorly developed by record keeping systems such as Dairy Comp 305® (Valley Software, Tulare, CA) and the Dairy Herd Information Association (DHIA) records. It is important to point out that the deficiency is not due to a failure of trimmers to collect the information; rather, the problem lies with our inability to efficiently transfer this information to herd records where further analysis could occur and is shown Figure 19.13.

A second problem with lameness data is that it lacks uniformity. Trimmers throughout the country use different terms in their description of foot conditions. Claw conditions such as ulcers and white line disease are collectively referred to as sole abscesses or laminitis. So, even though a trimmer's information may be available

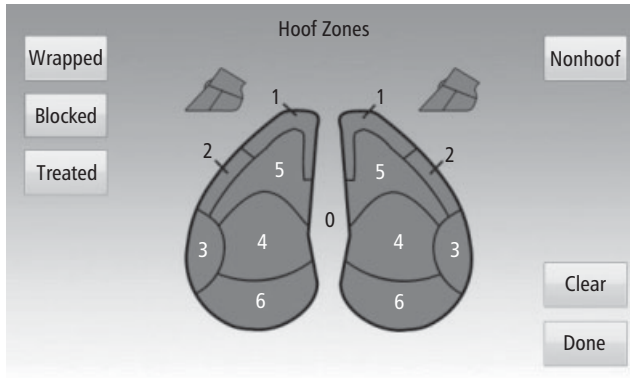

Figure 19.13. Hoof Zones on Hoof Supervisor 1 (KS Dairy Consulting, Inc., Dresser, WI). Hoof Supervisor on-screen display of claw zones that are activated by simply touching the screen to identify the zone affected which corresponds to the most likely lesion.

for review, it may be very difficult to interpret since terms used are not specific or in the worst-case scenario, are erroneous or unknown. This is complicated still further by the fact that trimmers, particularly those who are employed by the dairy, may be multicultural in origin and therefore less familiar with English terms for various conditions.

To address these challenges, Florida researchers developed the idea of capturing lameness information through the use of a touch-screen computer technology. Using the claw/foot zone diagram first introduced by Greenough and Weaver at the International Lameness Symposium in Rebilt, Denmark, researchers worked with software developers at Feed Supervisor to develop Hoof Supervisor (KS Dairy Consulting, Inc., Dresser, WI), a touch-screen computer technology that offers chute-side entry of lameness information (Fig. 19.14). Since Hoof Supervisor utilizes the claw/foot zone diagram which has been incorporated onto the computer touch screen, trimmers need only touch the claw/foot zone affected to record information. There is no need to identify the lesion by name since identification of the claw/foot zone does that automatically. For example, lesions occurring in zone 4 are sole ulcers, lesions in zone 3 white line disease, and so on. The system is language neutral and the information entered is uniform shown in Figure 19.14.

Lameness information is easily transferred to herd records (i.e., compatible with Dairy Comp 305) and analysis is simplified as the program will automatically provide pie charts or histograms of lameness conditions for interpretation by herd consultants. The software accepts radio frequency identification (RFID) transmission so that cow numbers can be recorded automatically using the RFID wand or a plate reader. The software

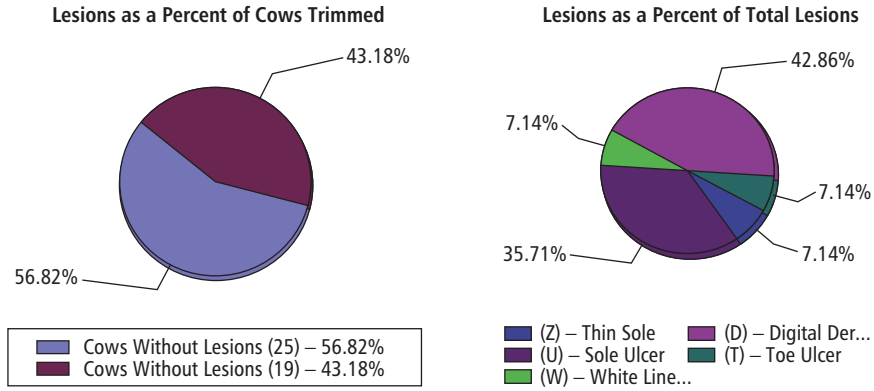

Figure 19.14. Display of foot care data 1: Display of foot care information by Hoof Supervisor. There are several options for display of foot care information.

for Hoof Supervisor is incorporated into a computer designed for use in extreme weather conditions that is rugged enough to withstand a drop of 4 ft. The use of this system provides both efficient and accurate capture of cow number and lameness information so that trimmers are not required to keep handwritten records which are subject to transcription errors and legibility problems. With the collection of accurate data and a system designed to streamline analysis, veterinary consultants and others are able to provide a better interpretation of foot health on dairies.

Use of Information on Lameness

Information captured on individual lame cows is useful for the management of their specific conditions or as a means for determining when culling may be necessary. For example, trimmers may use individual records to evaluate treatment outcomes, to identify cows for reevaluation, or to monitor cows with potentially serious lesions that may require veterinary assistance. Record keeping systems such as Hoof Supervisor will also track costs associated with foot care for individual animals as well as the herd.

On a herd basis, records may be used to generate lists of cows for maintenance trimming. Data on frequency of lesion occurrence can be used to evaluate seasonal trends or the effect of parity, stage of lactation, age, or other parameters on the incidence of lameness. For example, by noting the number of cases of DD that are presented to the trim chute per month, one can make a general assessment of the effectiveness of foot-bathing procedures. Further analysis of these data by parity, stage of lactation, and so on can help to pinpoint problem areas or groups of animals so that treatment and control strategies can be directed accordingly.

Lameness is by any measure of disease costs, one of, if not the most economically important diseases of dairy cattle. Our lack of information has impeded our progress to improved management of these conditions. These recent advances in methodology to capture this information along with better systems for analysis and interpretation of lameness data are essential steps in the successful management of these disorders on dairy farms.

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20

Management Strategies for Optimizing Forage Quality for Dairy Production

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Abstract

This chapter begins by describing the importance of forage in dairy cattle rations and summarizing the challenges and benefits of using grazed forage and green chop in dairy cattle production systems. More detailed discussions of hay and silage production are presented because of their wider use in dairy cattle rations in the United States. Particular attention is given to factors affecting the nutritional quality of forage. However, poorly made hay and silage can result in various diseases of both cattle and humans. Therefore, microbial and other factors that can make these otherwise safe forages hazardous or pathogenic are also discussed. Sections on each type of forage are concluded with a discussion of management factors that are necessary for optimizing their nutritional quality, shelf life, and safety.

Introduction

Forage is an important component of dairy cow rations for several reasons, the main one being provision of energy in the form of digestible fiber. The saliva produced when cows chew and ruminate on forage buffers acidity resulting from ruminal fermentation of grains in the diet. This reduces the incidence of acidosis and associated complications such as lameness and displaced abomasums. Furthermore, dietary forage is necessary for adequate milk fat synthesis and formation of the ruminal fiber mat, which traps ingested feed particles and facilitates their fermentation by ruminal microbes.

Pasture Forage

The main pasture grasses fed to dairy cattle in the United States can be classified as warm- or cool-season grasses, based on the differences in their photosynthetic pathways. Cool-season grasses, or C_3 grasses, are generally more digestible than warm-season grasses because they contain a greater proportion of mesophyll tissue and intercellular air spaces (Wilson, 1993). Important examples of cool-season grasses in the United States include ryegrass, bromegrass, and tall fescue. Warm-season or C_4 grasses like bermudagrass and bahiagrass use water, carbon, and nitrogen more efficiently and are more productive than C_3 grasses (Hanna & Sollenberger, 2007). However, C_4 grasses are less digestible because they have greater proportions of lignified, thick-walled parenchyma bundle sheaths (Wilson, 1993). Higher temperatures increase lignification and cell wall concentration; therefore, high tropical and subtropical temperatures contribute to the poorer nutritive value of warm-season grasses (Coleman et al., 2004).

Grazed forage is more nutritious than stored or conserved forage, yet most U.S. dairies harvest forage during periods of abundant growth and conserve them as hay or silage for a number of reasons. First, managing dairy cows on pasture requires adequate pasture acreage and appropriate pasture management skills, and is subject to fluctuations in the quality of the available pasture. Second, feeding conserved forage to cattle reduces the influence of inclement weather on forage availability and quality and cattle productivity. This chapter focuses on

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the management of harvested forage because of its widespread use for dairy production in the United States.

Green Chop

Green chop forage refers to harvested forage fed fresh to cows on the day of harvest. The benefits of timely feeding of green chop to cows include harvesting the forage at a maturity that optimizes nutritive value and avoids cost and nutrient or dry matter (DM) losses associated with hay or silage production (Vander Horst et al., 1998). In addition, this practice allows cattle to be housed and reduces the need for grazing management experience. However, the practice is labor-intensive and requires proximity of cattle barns to pastures. Yields of green chopped forage may be lower than normal, and moisture content will be higher if the forage is harvested at immature stages to optimize nutritive value. Green chop is also dependent on the consistent functioning of equipment for harvesting and transporting the forage.

Hay Production

Hay is the product of wilting or sun-drying harvested forage to moisture concentrations that inhibit microbial growth. Hay drying periods range from a few hours to several days depending on plant characteristics such as stem diameter and plant moisture concentration at harvest as well as the prevailing temperature, solar radiation, humidity, and rainfall. During drying, continued plant respiration and microbial action results in losses of protein- and water-soluble carbohydrates, chlorophyll, and carotene, but vitamin D concentration increases (McDonald et al., 1995). Mechanical damage during hay making and leaching during storage may cause further DM losses. Consequently, the nutritive value of hay is often lower than that of freshly harvested grass.

Dangers Associated with Inadequately Dried Hay

After the hay is harvested with a mower or swather, it is arranged in windrows, dried, and rolled into round bales or packed into square or rectangular bales. Baling inadequately dried hay predisposes to the growth of thermophilic microbes instead of the normal mesophilic microbes (Slocombe & Lomas, 2008). Growth and activity of the thermophiles can generate high temperatures (>150°F) that lead to protein denaturation, formation of indigestible Maillard products, and reduced protein availability. Furthermore, the high temperatures generated can cause spontaneous combustion of hay bales and engulfment of hay barns and neighboring property in flames. Inadequate drying can also predispose to the growth of molds and actinomyces that cause farmer's lung in hays (Wild & Chang, 2009). In addition to directly causing diseases when inhaled or ingested, molds reduce forage palatability and produce mycotoxins, which can reduce the productivity and health of dairy cattle and cause various illnesses in humans. Therefore, one of the most critical factors in hay production is rapid drying or wilting of the plant to a DM concentration of 85%–90% or more before baling. Ideal hay production conditions include high temperatures, high solar radiation, and low relative humidity. Consequently, despite having high summer temperatures, hay making in tropical and subtropical areas is hampered by high relative humidity and frequent rainfall.

Increasing the Rate of Moisture Loss from Hay

Various mechanical, chemical, and other techniques for increasing moisture loss during hay making have been investigated, but only mechanical techniques have proven practical for extensive use (Rotz & Shinners, 2007). Several types of equipment have been developed to hasten the drying rate. Tedders are used to fluff and spread out the hay in windrows to facilitate drying, and the tedded forage is raked into windrows before baling. Mowers may be equipped with conditioners or crimpers, which are steel flails that cut and crimp the crop and break the cuticle to enhance the rate of moisture loss. Inverters are also used to overturn and aerate forage in windrows to facilitate drying. In some countries, hay is made on tripods or frames to facilitate aeration. Many of these processes can considerably increase the forage drying rate, but some may also increase leaf shatter and fine particle loss or contaminate the forage with sand. These problems can decrease the protein concentration of forage and increase the ash concentration, respectively.

Management Strategies to Optimize the Quality of Hay

Various strategies are required to maximize the nutritive value, yield, and hygienic quality of hay. First, location-appropriate improved forage species and cultivars should be selected, depending on the needs of the production system. Excellent agronomic practices are needed to ensure that forage fields achieve their full growth potential and are free of weeds. Maturity at harvest is perhaps the most important factor to optimize the nutritive value and yield of hay. Various agronomic indices have been developed to indicate the optimal maturity at harvest for

different forage types destined for hay production. For instance, alfalfa is often harvested at the mid- to late-bud stage, whereas bermudagrass should be harvested at 4- to 5-week regrowth intervals. Careful attention to these indices is critical to optimizing the quality of hay. Strategic application of nitrogen fertilizer a few weeks before the anticipated harvest date can increase forage crude protein (CP) concentration, but the return on this investment should be carefully evaluated for each system.

Hay production should be planned after careful examination of weather forecasts to avoid harvesting on rainy or humid days or when dew is on the forage. Once mown, forage should be wilted for an appropriate duration to achieve a DM concentration of 85% or more in the shortest possible time. Drying aids should be used where necessary as long as they do not excessively compound leaf or DM losses or contaminate the forage with sand.

Additives may also be added at harvest to minimize spoilage and increase the nutritive value of hays. Propionic acid is a strong antifungal agent that has successfully been used to prevent mold growth and heating of hay when applied at rates of 1%–2% of hay fresh weight (Rotz et al., 1991). Injection of anhydrous ammonia at the rate of approximately 3% into bales of hay wrapped in plastic is a particularly effective strategy for reducing heating and mold growth in hays and increasing the CP concentration and digestibility of hays. Appropriate safety precautions are required for handling ammonia and organic acids because of their corrosive nature. Buffered organic acids are less corrosive but may be as effective as propionic acid when equivalent amounts of propionate are applied provided they are applied at relatively high rates (≥1%) (Rotz et al., 1991). Spraying solutions of urea on cut ends of hay bales has offered some of the benefits of ammoniation without the potential hazards (Brown & Adjei, 1995). Various lactic acid bacteria inoculants and/or enzymes have been applied to improve the quality of hays, but the results have been variable (Rotz & Shinners, 2007; Krueger et al., 2008).

Hay bales need to be stored adequately to minimize losses in quality and susceptibility to deterioration and mold growth during storage. Nutrients in uncovered hay bales are subject to being leached out by rainfall, and such losses can be more than twice as much as those from hay stored in a covered shed (Table 20.1). Keeping hay bales in an enclosed barn is the best way to preserve quality and minimize adverse effects of the weather, pests, and spoilage microorganisms on the hay (Rotz & Shinners, 2007). If this is not feasible, hay bales should be stacked in a pile on a well-drained area in the field and covered with a tarp or suitable plastic sheet.

Table 20.1. Typical dry matter losses and nutrient changes during hay harvest and storage operations (Adapted from Rotz & Shinners, 2007)

	Average DM loss (% DM)	Change in nutrient concentration (percentage unit)		
		CP	NDF	DDM
Legumes				
Mowing	1	–0.4	0.6	–0.7
Tedding	3	–0.5	0.9	–1.2
Raking	5	–0.5	1.0	–1.2
Baling (large round)	6	–1.7	3	–4.0
Hay storage inside	5	0.7	2.1	–2.1
Hay storage outside	15	0.0	5.0	–7.0
Grasses				
Mowing	1	0.0	0.0	0.0
Tedding	1	–0.2	0.4	–0.4
Raking	5	–0.3	0.5	–0.6
Baling (large round)	6	–1.0	1.8	–2.0
Hay storage inside	5	–1.3	3.2	–1.8
Hay storage outside	12	0.0	8.0	–4.8

CP = crude protein; NDF = neutral detergent fiber; DDM = digestible dry matter.

Recently, attention has focused on wrapping high-moisture (50%–70%) bales of hay in plastic to produce haylage. The main advantages of producing haylage instead of hay are that less moisture needs to be lost from the forage, shorter harvesting windows are required, less leaf and DM losses occur, and bales are protected from rainfall when stored outside (West & Waller, 2007). These factors increase the recovery of digestible nutrients in haylage and increase flexibility in timing of harvest (West & Waller, 2007). To realize these benefits, forage destined for haylage production should be harvested at the appropriate maturity stage for the specific type of forage, wilted to 50%–65% DM before baling, and wrapped immediately after baling with six to eight layers of 6–8 mil plastic wrap. Wrapped bales should be stored for at least 3 weeks in well-drained areas where puncture of the plastic by cattle or pests is unlikely and should be fed within 2–4 days of opening the bale to minimize spoilage.

Silage Production

Silage is the product of bacterial fermentation of monosaccharides and disaccharides in forage stored under

Table 20.2. Acidification and fermentation efficiencies of main fermentation pathways of silage bacteria (adapted from Rooke & Hatfield, 2003)

				% Recovery	
Organism	Pathway	Substrate	Product(s)	Energy	DM
LAB	Homofermentative	Glucose	2 lactate	96.9	100
LAB	Heterofermentative	Glucose	1 lactate + 1 acetate + CO_2	79.6	83
LAB	Heterofermentative	Glucose	1 lactate + 1 ethanol + CO_2	97.2	83
Yeasts		Glucose	2 ethanol + CO_2	97.4	51
Clostridia		Glucose	1 butyrate + CO_2	77.9	66
Ent		2 glucose	2 lactate + 1 acetate + 1 ethanol + CO_2	88.9	83

LAB = lactic acid bacteria; Ent = enterobacteria; DM = dry matter.

anaerobic conditions. Silages are a key component of the rations of most dairy cows in the United States. Their main roles are to supply energy from digestible fiber and fermentable carbohydrates, to buffer ruminal acid production by facilitating salivation, to enhance milk fat synthesis, and to maintain the rumen mat that facilitates ruminal microbial fermentation of dietary nutrients. Corn silage is the most widely used silage in dairy cow rations in the United States due to its high fermentability and high energy value. Other important silages are made from alfalfa, small-grain cereals, and warm- and cool-season grasses.

Silage making involves harvesting and chopping forage, as well as transporting it to sites where it is unloaded and consolidated in a silo and properly sealed to prevent subsequent oxygen ingress. Common silo designs in the United States include bunkers, bags, drive-over-piles, and tower silos, but in other countries, pit and small-bag silos are common.

Silage Fermentation

During ensiling, fermentable sugars in plants are fermented into organic acids by anaerobic bacteria. The acid production reduces the pH to 3.6–4.5 and inhibits the growth of less desirable microbes that degrade nutrients and interfere with normal fermentation. Growing plants contain various bacteria that either enhance or inhibit silage quality. Consequently, silage fermentation and quality is dependent on which type of bacteria dominates the fermentation. The most desirable bacteria are the homofermentative lactic acid bacteria that ferment plant sugars into lactic acid yielding no DM losses and negligible energy losses (Table 20.2; McDonald et al., 1991). The high efficiency of this pathway reflects the strength of lactic acid and its ability to more rapidly reduce the pH compared with other organic acids. Examples of such lactic acid bacteria include *Lactobacillus plantarum* and *Pediococcus pentosaceus*. A second group of bacteria ferment sugars via a heterofermentative pathway into several end products such as lactic, acetic, and propionic acids; alcohols; and CO_2. Consequently, DM and energy recovery can be lower with the heterofermentative pathway (Rooke & Hatfield, 2003).

The lactic acid formed during primary fermentation can be further fermented by *Clostridia* into butyric acid during a process called secondary fermentation, particularly when forage moisture concentration is high. This reduces the rate and extent of pH decline, and with enterobacteria, *Clostridia* also hydrolyze proteins and peptides and deaminate amino acids such that the quality of silage protein is reduced. Ironically, the high butyric concentration in clostridial silages increases the shelf life (aerobic stability) of silage due to its antifungal properties. However, butyric silages have pungent offensive odors that reduce intake of the silage by livestock.

Undesirable Microorganisms in Silage

Inadequate management during feedout (after the ensiling period is over) can lead to proliferation of aerobic organisms that may be pathogenic or cause heating and considerable losses of nutrients and DM. This section discusses effects of some of the main spoilage organisms in silage.

Yeasts

Yeasts are aerobic fungi that initiate aerobic spoilage in most silages (Pahlow et al., 2003) because they can grow under the acidic conditions that prevail immediately after silos are opened. Utilization of lactate by certain yeasts increases the pH and predisposes to the growth of opportunistic fungi and bacteria that worsen aerobic spoilage. Examples of lactate-utilizing yeasts include

those of the *Candida* and *Pichia* spp., whereas those of the *Saccharomyces* spp. do not utilize lactate (McDonald et al., 1991). Certain yeasts (e.g., *Saccharomyces cerevisiae*) can also ferment plant sugars into alcohol and CO_2 under anaerobic conditions. Consequently, high sugar forage types like sugarcane typically have an ethanolic fermentation.

Molds

Silage molds are opportunistic aerobic fungi that utilize nutrients such as sugars, protein, and cell wall components, decrease the palatability of silage (McDonald et al., 1991), and increase silage spoilage. In addition to such effects, *Aspergillus fumigatus* molds have been associated with aspergillosis and hemorrhagic bowel syndrome (Puntenney et al., 2003) in cattle. These diseases are associated with allergic reactions, pulmonary problems, and pneumonia, and reduced feed intake and milk production, intestinal hemorrhage, and bloody diarrhea, respectively. However, the most notorious effect of silage molds probably occurs via the mycotoxins they produce, which can cause various mycotoxicoses and symptoms such as reproductive problems, liver damage, abortions, and reductions in feed intake, growth, and milk production in cattle. Silage mycotoxins include those produced by *Penicillium* (PR toxin, mycophenolic acid, roquefortine C, patulin), *Fusarium* (deoxynivalenol, zearalenone, T-2 toxin), and *Aspergillus* species (aflatoxin, gliotoxin, fumitremorgens, fumigaclavines), but others may also be present (Whitlow & Hagler, 2009).

Mycotoxin production can occur during plant growth in the field or during ensiling. Delayed harvesting or filling, inadequate packing and sealing, slow feedout rates, and/or damaged bunker or bag plastic can lead to pockets of mycotoxin production (Whitlow & Hagler, 2009). Queiroz et al. (2009) showed that aflatoxin levels in rust-infested corn silage exceeded actionable levels stipulated by the U.S. Food and Drug Administration. Other diseases and insect damage of crops may also predispose to mycotoxin contamination.

Bacilli

Bacilli are facultatively anaerobic sporulating bacteria, and their endospores tolerate harsh environmental temperatures, including milk pasteurization and boiling temperatures (Pahlow et al., 2003). In some situations, *Bacillus* spp. have been implicated in causing aerobic spoilage of silages (McDonald et al., 1991), and in other cases they develop immediately after yeasts in deteriorating silages (Pahlow et al., 2003). *Bacillus cereus* spores can pass through the digestive tract intact, contaminate the milk of dairy cows, survive pasteurization temperatures, and decrease the shelf life of milk and cream (Pahlow et al., 2003). Furthermore, enterotoxins produced by this bacteria cause foodborne illnesses, notably emesis and diarrhea (Ankolekar et al., 2008).

Listeria

Listeria are opportunistic aerobic or facultatively anaerobic bacteria that cause high mortality rates and a wide range of diseases in immunocompromized animals and humans, including meningitis, encephalitis, septicemia, gastroenteritis, mastitis, and abortions (McDonald et al., 1991). *Listeria monocytogenes* is the main source of these diseases, and it is ubiquitous because it tolerates wide ranges in temperature, water activity, and pH (Pahlow et al., 2003). *L. monocytogenes* can be transmitted from contaminated silages into milk, but it is destroyed by adequate pasteurization (Griffiths, 1989).

Clostridia

Clostridia are soil-borne, mostly obligately anaerobic, sporulating bacteria that thrive in low-sugar silages particularly when there are high levels of plant moisture (>70%), pH (>4.6), temperature (>30°C), and buffering capacity. Those found in silage include saccharolytic types (e.g., *Clostridia butyricum* and *Clostridia tyrobutyricum*) and others that ferment both sugars and amino acids (e.g., *Clostridia sporogenes* and *Clostridia perfringens*) (Pahlow et al., 2003). Some of the biogenic amines produced during clostridial proteolysis are toxic, and virtually all have pungent odors and reduce intake, rumen motility, and growth of ruminants (Van Os et al., 1995; Phuntsok et al., 1998; Fusi et al., 2004). *C. perfringes* from silage was thought to cause hemorrhagic bowel syndrome, but this theory has been questioned (Dennison et al., 2002). Although the occurrence in silages is rare (Driehuis & Elferink, 2000), *Clostridia botulinum* can grow in silage and produce the neurotoxin when silage fermentation fails to achieve a pH less than 5.3 (Notermans et al., 1979). Clostridial spores transmitted from silage into milk can cause a butyric fermentation that causes late blow of dairy products (McDonald et al., 1991). This is characterized by a rancid odor and tainted flavor in milk and outgrowths that can double the size of cheese (Cocolin et al., 2004).

Enterobacteria

Enterobacteria are gram-positive, facultatively anaerobic bacteria that compete with lactic acid bacteria for water-soluble carbohydrates when the pH is high (>6.5; McDonald et al., 1995). Although *Erwinia* spp. are commonly found in silage, the most notorious member of

the genus *Enterobacter* is *Escherichia coli* O157:H7. Silage can be contaminated with the pathogen via manure or irrigation water (Weinberg et al., 2004), but the pathogen is usually eliminated when the pH drops below 4–5 during ensiling (Bach et al., 2002; Chen et al., 2005; Pedroso et al., 2010). However, high pH during silage feedout may encourage its growth (Reinders et al., 1999; Queiroz et al., 2009). Like *Clostridia*, enterobacteria deaminate and decarboxylate amino acids in silages, thereby enhancing ammonia and biogenic amine production and increasing the risk of depressed intake and inefficient nitrogen utilization by livestock.

Accumulation of toxic levels of nitrates in ensiled forage can decrease the oxygen-carrying capacity of the blood or cause reproductive problems and fatality in cattle and humans (Hill, 1999; Weinberg et al., 2004). Silage enterobacteria are usually effective at degrading nitrates (McDonald et al., 1991), but they convert them into oxides of nitrogen, which cause a respiratory problem in farm workers known as "silo fillers disease" (Weinberg et al., 2004). Muck and Kung (2007) noted that inhalation of small quantities of nitrogen dioxide (NO_2) and nitrogen tetraoxide (NO_2O_4) can cause chronic pulmonary problems or fatality and emphasized that beef or dairy producers should stay away from silages within the first 3 weeks of ensiling when these compounds are produced.

Management Strategies for Improving Silage Quality and Hygiene

Several management practices are necessary to ensure that hygienic, high-quality silages are fed to livestock. Only forage types with high water-soluble carbohydrate to buffering capacity ratios are ideal for ensiling. Crops with low ratios may have insufficient sugars or excessive buffering for an ideal fermentation to occur. Harvesting at the maturity stage that optimizes DM concentration, nutritive value, and yield is also particularly crucial during silage production. Harvesting forage too late could predispose to spoilage because of the increased occurrence of air pockets that favor growth of yeasts and molds. Harvesting too early results in the production of effluent. Effluent seepage into waterways can cause significant loss of marine life due to its high biological oxygen demand. Consequently, forage moisture concentration should be determined to accurately predict when to harvest different forage types for ensiling. Ideal moisture concentrations at harvest vary with forage type. For corn, cool-season grasses, legumes, and warm-season grasses, DM concentrations contents of 30%–35%, 30%–35%, 40%–45%, and 40%–45%, respectively, have resulted in successful silage production. When standing crops are harvested at higher moisture concentrations, they should be field-wilted to avoid clostridial fermentation.

Harvested forage should be chopped to an appropriate size that facilitates compaction in the silo but ensures that the integrity of the fiber is not compromised. In certain cases, cereal grain silages need to be processed or crushed to rupture the grain seed coat and ensure that fermentable carbohydrates in the grain are available to the livestock. This is achieved by passing the forage through two closely spaced rollers in a forage harvester. In such cases, longer chop lengths may be necessary to maintain the integrity of the fiber.

During silo filling, the forage should be spread in thin layers, not exceeding 15 cm for bunker silos, and compacted to achieve densities of about 240 kg DM/m^3 or more because at high densities, oxygen is adequately excluded from silages and the fermentation is optimized. Immediately after the silo is filled, the sides and top of the silage mass should be covered with plastic sheets and the top sheet weighted down with tires or sand bags to prevent entry of oxygen.

During the feedout stage, strategies that minimize entry of oxygen into the silo are critical; therefore, silo design should aim to minimize the size of the silo face. Any holes in the silo plastic or cracks in the silo wall should be immediately sealed (Muck & Kung, 2007). Maintenance of a straight silo face is necessary for minimizing oxygen ingress and heating. Mechanical devices such as shavers and block cutters can be effective for this purpose. A rapid silage feedout rate is also important to reduce the duration of exposure of the silo face to oxygen. Rates of at least 15 cm/day have been advocated for this purpose (Muck et al., 2003; Whitlow & Hagler, 2009).

Some additives have been successfully used to improve the quality of hays and silages. For instance, ammonia treatment at rates of about 1% may hydrolyze lignopolysaccharide linkages in forage, increase nitrogen concentration, and inhibit mold growth. Higher rates may inhibit the fermentation and predispose to formation of 4-methyl imidazole, which can be toxic to cattle. Formic and sulfuric acids have been used to improve silage fermentation, and propionic acid application reduces heating during feedout. Buffered acid products that are less hazardous are now commonly available, and many are effective for improving aerobic stability when applied at 2–3 g/kg of fresh weight (Kung et al., 2000).

Bacterial inoculants used in forage preservation can be classified according to their purposes. Homolactic inoculants contain bacteria that ferment water-soluble carbohydrates to lactate. This rapidly decreases the pH and minimizes DM and energy losses. Heterolactic inoculants contain bacteria such as *Lactobacillus buchneri*,

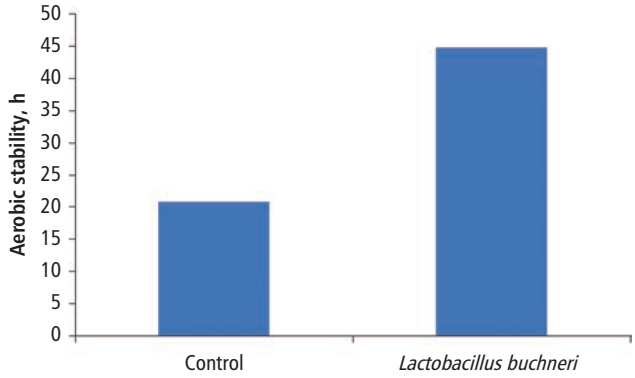

Figure 20.1. Effect of a *Lactobacillus buchneri* inoculant on the aerobic stability of corn silage (Pedroso et al., 2010).

which may result in a more gradual fermentation but increase the production of antifungal compounds like acetic acid that increase aerobic stability, as shown in Figure 20.1. Combinations of both types of bacteria are also available. Generally, inoculation rates of 10^5 cfu/g of fresh forage are necessary for bacterial inoculant efficacy.

Summary

Forage is an important source of energy, and various nutrients and can be strategically used in dairy cattle rations to improve rumen function, performance, and health. However, harnessing the potential of forage for nutrient supply requires a proper understanding of how plant, climatic, and edaphic and management factors combine to influence their yield and quality. Stored forage is more widely used than grazed forage in many dairy production systems but is more likely to be hazardous or pathogenic when not properly produced. Therefore, excellent hay or silage management practices are indispensable to ensure that such forage types are hygienic, safe, and highly nutritious.

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21

Applied Statistical Analyses for Dairy Production

Pablo J. Pinedo

Abstract

Data analysis is an important component of management in current dairy production systems. Applied statistical analysis and basic epidemiological notions represent valuable instruments for the routine work of the dairy practitioner. This chapter attempts to provide some basic statistical and epidemiological concepts and familiarize veterinarians with the common terminology and procedures that could be applied in the practical analyses of farm information.

Introduction

Dairy production systems have gone through dramatic changes during the last decades, with a shift in the emphasis from the individual to the population. Production medicine is characterized by an integrated, proactive, data-based, and economically framed approach to prevention of disease and enhancement of performance (LeBlanc et al., 2006).

In this context, with increasing frequency the dairy practitioner is expected to analyze and interpret numerical data generated from the application of herd health programs in the dairy farm. In a daily basis, considerable information is generated on farms in the form of routine reports, "on-farm" software, or performance monitoring programs such as Dairy Herd Improvement Association (DHIA) (Ruegg, 2006). However, for diverse reasons, in numerous cases substantial benefit from this data is not obtained. On the other hand, current scientific literature in dairy science and veterinary medicine bases the analysis of the data in statistical methodologies that may require some preliminary knowledge from the dairy practitioner for a critical interpretation.

This chapter provides an overview of the more common concepts used in statistical and epidemiological analyses. The objectives are to familiarize veterinarians with the common terminology and methodologies utilized in data and epidemiological analysis and to clarify some concepts that could be applied in the practical analyses of acquired farm data.

Nature of the Data

Depending on their nature, variables can be classified in two groups: qualitative and quantitative. Qualitative (categorical) variables include data that fit into a set of categories that may be classified as binomial (the outcome will be yes/1 or no/0) or may include multiple categories. Examples are the possible outcome of pregnancy, the occurrence of dystocia, death, or paratuberculosis infection. When there is an inherent order among the categories, the data are referred to as ordinal. This could be the case of the severity of a disease (none, mild, or severe diarrhea). When categorical variables have unordered scales they are called nominal variables (Agresti, 1996). Quantitative data measures the quantity of a particular variable. These observations may be expressed on a continuous scale (with all the possible values between two points; e.g., milk yield) or in a discrete scale where variables can only take integer values

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Table 21.1. Statistical test and nature of data

Nature of the outcome variable	Example	Test that apply
Quantitative	Calf weight, milk yield	*t*-test, ANOVA, correlation, regression analysis
Qualitative (categorical)	Presence of metritis, paratuberculosis infection, culling, death	Chi-squared test, logistic regression, survival analysis

(days to conception). Quantitative variables reported in numerous studies are milk protein, services per conception, somatic cell count, bacteria count, feed weigh back, or body weight. The nature of the response (dependent) variable is crucial in the selection of the adequate statistical test and is shown in Table 21.1.

Summarizing Data and the most Common Distributions

There are three most commonly used statistics for summarizing data: mean (average), median, and standard deviation (SD). The average and the median are used to determine the center (central tendency) of a series of data, and the SD measures spread (dispersion) around the average (Freedman et al., 1998). The average corresponds to the sum of the observation values divided by how many they are. This statistic will appear many times in the DHIA farm report summarizing daily milk production per cow, days to first service, or services per conception by parity. The median is the middle observation; the one that divides the distribution of values into halves (Dawson & Trapp, 2004). However, what the average and the median fail to inform is how spread are the data around the central value. Daily milk yield may be very homogeneous among the cows in a herd or may be grouped into two high- and low-producing subpopulations with considerable variability. Still, the average will be the same in both situations. Therefore, although averages are very informative, they lack a piece of the picture. The SD provides this information and is defined as the square root of the average of the squared deviations of the observations from their mean (Moore & McCabe, 2003).

Depending on the nature of the variable, the data may disperse around the mean in different forms, creating different frequency distributions. The most common distribution is the normal curve which is a symmetric, bell-shaped probability distribution (Dawson & Trapp, 2004). If a list of values follows the normal distribution, most of the entries will be somewhere around one SD away from the average, and very few will be more than two SD away. Milk yield and body weight at first breeding are two good examples of variables following close to normal distributions. If an event can have only binary outcomes (e.g., yes or no), then data will follow the binomial distribution. This distribution is used to estimate the probability that a specific outcome occurs in a given number of independent trials (such as the probability of head after flipping a coin 100 times).

Probabilities and Significance

A key concept in data analysis is probability, which is defined as the number of times an outcome occurs in the total number of trials (Dawson & Trapp, 2004). Every outcome from a trial using a sample obtained from a population is associated to the probability that the results represent the true value in the population from which the sample was drawn. Given that samples are not identical to the population from where they were selected, it is important to assess the degree of accuracy to which the sample mean or sample proportion represents the corresponding population value (Ott & Longnecker, 2001).

Statistical significance is a term used very often in research and indicates how likely a result is due to chance. The most commonly used level of significance is 95% (usually expressed as a *P*-value of 0.05 or 5%) which means that if a trial is repeated 100 times, in 95 of the cases the results will point to the same conclusion. In other words, there is a 5% chance that the difference (treatment, variable effect, etc.) measured was due to random variation; there is a 5% probability that a particular outcome was due to only chance (Slenning, 2006).

An important concept associated with the application of statistical inference relates to the possible errors when testing a hypothesis: the type I and type II error. A type I error is defined as the rejection of the null hypothesis (that assumes no difference or effect) when it is really true. Alpha (α; 1—significance level, *P*-value) is the probability of making a type I error. In simple words, this is the probability of erroneously concluding a difference when none exists.

Conversely, a type II error consists in not rejecting the null hypothesis when it is in fact false (β error). Two very important concepts associated to the type I and II errors are power and the *P*-value. Power is defined as the probability of rejecting the null hypothesis when it is indeed false or appropriately concluding that the alternative hypothesis is true (power = 1—type II error) (Dawson & Trapp, 2004). The *P*-value is the probability of obtain-

ing a statistical test result as extreme as the one observed if the null hypothesis is true. Again, it is the probability that the differences obtained are due to chance. Most of the researchers consider an error chance of 5% acceptable.

In this context, a confidence interval (CI) is associated with the values estimated by statistical tests. The CI is provided as the resultant estimation ± a margin of error. This range gives the probability that the interval covers the parameter (the true value) and depends on the significance level considered for the test. Consequently, with the massive use of a *P*-value of 0.05 (5%), by far the most common CI is associated with a significance level of 95% and therefore is expressed as 95% CI. In practical terms, this means that, given the level of variability in the data, if we repeat our estimation multiple times, 95% of those times the true value (mean, proportion, odds ratio (OR), etc.) will be within our confidence interval.

Comparing Groups

Means and Proportions

The approach to group comparisons mainly depends on three elements; the nature of the data (qualitative vs. quantitative), how it is distributed (normal, binomial, etc.), and the number of groups to be compared.

When the concern is to analyze a quantitative variable, a very usual question refers to the difference between the means of two groups. A first approach is the use of the *t*-test. However, three assumptions are needed for the use of the *t* distribution: observations in each group follow a normal distribution; the SDs of the two groups should be equal; and observations in one group are independent from the other group (Dawson & Trapp, 2004). When one of these assumptions is violated, transformation of data (e.g., to a log base) or nonparametric tests may be used (e.g., Wilcoxon rank sum test). A good example of the use of the *t*-test is provided by Proudfoot et al. (2009) when analyzing the effect of dystocia on behavior of Holstein cows. The time to first meal after calving was measured in affected vs. nonaffected cows. The estimated *t*-values indicated that the average time to first meal was shorter for dystocia cows compared to eutocia cases ($P = 0.01$).

If the outcome is a categorical variable, the approach is different. Now we have counts or frequencies for a particular outcome in the different groups. For example, counts for the presence of subclinical ketosis in fresh cows with body condition scores above or below 3.5. The question will be whether the proportion of ketosis is different for the two body condition groups. If two groups is the case, then the *z*-test can be used. When frequencies in two or more groups are compared, the chi-squared (χ^2) test can be applied. In this case, the independence between two variables will be tested, and the question will be if one variable that divides the population in groups is associated to the frequency of a particular outcome in each of these groups. Contingency tables are very practical and can help in the interpretation of categorical data; an example is shown in Table 21.2. An example for the application of the chi-squared analysis is provided by Gulay et al. (2007) when testing the effect of bovine somatotropin supplementation on calving-related diseases. Their results indicated significant differences between the bST-supplemented and control groups in the number of animals affected for clinical mastitis, digestive problems, and ketosis, with a greater number of healthy cows in the bST-supplemented group. In another study, (Hernandez et al., 2005a) the proportions of cows that left the herd during lactation were compared among nonlame cows, moderately lame cows, and lame cows by use of a chi-squared test. No difference was found among these three groups ($P = 0.97$).

Table 21.2. Contingency table for paratuberculosis true status (indicated by fecal culture) and serum ELISA results

	Truly infected	Noninfected	Total
ELISA positive	28	9	37
ELISA negative	22	78	100
Total	50	87	

ELISA = enzyme-linked immunosorbent assay.

When the outcome is numerical and the idea is to compare means in three or more groups, the preferred approach is the analysis of variance (ANOVA). If the result of the ANOVA is significant, it indicates the means of at least two groups are different and comparisons among pairs or combinations of groups can be made (Dawson & Trapp, 2004). As for the *t*-test, when using ANOVA, some assumptions must be accomplished: The outcome variable has to follow a normal distribution; the variance must be the same for each of the groups; the observations are a random sample, and they are independent. If the assumptions are not accomplished, an alternative nonparametric test may be used (e.g., Kruskal–Wallis one-way ANOVA).

Repeated Measures

In some cases, data contain multiple measures on the same dependent variable for each individual under different treatment conditions or over time. This could be seen as a sequence of different trials, where each trial represents the measurement of the same characteristic

under a different situation. A simple example could be the difference in daily milk production between cows receiving a particular nutritional additive and control cows over a period of time. In such cases, given that the same individuals are tested multiple times, the observations of the outcome variable are no longer independent (they are correlated), and consequently, this needs to be considered.

In dairy production, measures in the response variable may also be correlated in space and/or time. Cows clustered within a herd are an example of observations correlated in space, and infection status in infected quarters during lactation represent observations correlated in time (Gröhn et al., 1999). Repeated measures methodology was used to model the effect of ketosis on milk yield in Holstein cows. Ketosis had no effect on 305-day milk yield. However, the effect was significant on test-day milk yields, indicating the advantage of accounting for repeated measurements on the same individuals (Gröhn et al., 1999).

Association Among Variables

In some cases, the focus of the analysis is placed on testing the association among variables or in predicting the response (dependent variable) based on values of explanatory (independent) variables.

Correlation and Regression

Correlation analysis applies when the purpose is to measure the extent of an association between two numerical variables (in this case the linear relationship). The product is the correlation coefficient (r) that ranges from −1 to +1, indicating a perfect negative or positive linear relationship. Consequently, a correlation coefficient value of 0 indicates no linear association between the two variables (Dawson & Trapp, 2004). As a reference, correlations from 0.5 to 0.75 (or the corresponding negative values) indicate a moderate association; values greater than 0.75 show a very good relationship. When the correlation is squared (r^2), the coefficient of determination will indicate the proportion of the variation in one variable that can be accounted for by knowing the value of the other variable.

When the aim is not only to test an association among variables but also to predict a value in the response variable, the linear regression analysis is indicated. In this case the product will be an equation for predicting the value of the response from values of the explanatory variables (Dawson & Trapp, 2004). If only one explanatory variable is considered in the equation, the term simple regression is used. In multiple regression two or more explanatory variables are considered. Again, the use of regression analysis requires that some assumptions are observed: for each value of the explanatory variables the response variable must follow a normal distribution. Similarly, at these points, the SD should be the same. There is also a requisite of linearity in the association between the response and the explanatory variable, and the values for the response variable are assumed to be independent from each other (Dawson & Trapp, 2004).

An example of the application of simple linear regression analysis is the positive association found between dam height at freshening (centimeters) and calf weight at birth (kilogram) that was presented by Linden et al. (2009). In this case a value for $r = 0.4$ resulting from correlation analysis indicated a moderate linear association. In another study, multivariate regression analysis was used for testing the effect of lameness on milk 305-day milk yield (Hernandez et al., 2005b). Three levels were determined for lameness score: low, medium, and high. After adjusting for potential confounding variables, the analysis indicated that cows with high scores produced 747 kg less milk than cows with low scores ($P = 0.01$). Variables included in the model explained 10% of the variation in milk yield ($r^2 = 0.10$).

Logistic Regression

This procedure is commonly used in dairy research when the explanatory variables include numerical and categorical data and the response is categorical (in most of the cases binomial: success/failure; yes/no). The most widespread interpretation of the logistic regression model uses the odds and the OR. The odds are defined as the probability that an event will occur divided by the probability that the event will not occur [p/(1 − p)]. Therefore, the OR is a method of comparison of odds for different levels of a particular factor. This is the ratio of the odds of an event occurring in one group to the odds of it occurring in another group. An important advantage of logistic regression relates to situations in which the explanatory variable is random, as is the case for retrospective study designs, such as case-control studies (Agresti, 1996).

The value for the OR must be greater than or equal to zero, with a value of 1 indicating no association between the event under analysis and the explanatory variable. Values less (greater) than 1 indicate a negative (positive) association, and the farther from 1 is the OR, the stronger is this association. As in the previous statistical tests, the OR estimation is associated to a significance level. Very often the ORs are presented with an associated 95% CI; as a practical indication, when this interval includes

the value 1, the estimation is not significant at the 0.05 level.

An application of logistic regression was presented by Moore et al (1991) in an evaluation of potential risk factors for early embryonic loss in dairy cattle. In the study the outcome variable was dichotomous (embryo loss yes/no). Among others, the independent variable of interest was clinical and subclinical mastitis (somatic cell score > 4.5) in the proximity of artificial insemination. An OR = 2.4 indicated that if a cow had subclinical mastitis before breeding, it was 2.4 times as likely to lose the embryo from days 28 to 35, compared with cows that did not have mastitis. Another example is the use of logistic regression in the analysis of the impact of dystocia on health and survival of dairy calves (Lombard et al., 2007). Results indicated that the odds of a heifer calf being born dead or dying before 120 days were increased for severe dystocia when compared to heifers that received nonassistance during calving (OR = 6.7). In other words, the odds of dying around calving for heifers born after severe dystocia were 6.7 times the odds of dying for heifers born from unassisted calving. The 95% CI was 4.9–9.2, which is an indication of statistical significance for the estimation ($P \leq 0.05$). The key here is that the CI does not include the value 1.0.

Time Analyses

One of the main procedures in this category is the survival analysis that refers to the study of data in the form of time intervals from a well-defined time origin until the occurrence of a particular event or end point (Collet, 2003). The method was designed for the study of deaths after the diagnosis of medical conditions but today is applied to the analysis of event occurrence in multiple fields. Although survival analysis can be applied to data consisting only of the times of events, a more common approach is to estimate predictive models in which the risk of an event depends on covariates (Allison, 2004). Two main attributes of survival analysis are censoring and time-dependent covariates. Censoring mostly relates to missing data and is divided into right and left censoring. Right censoring occurs when the end point of interest has not been observed for an individual. This is the case for individuals that at the time of the data analysis have not suffered the event of interest (they have "survived"). This is also the case for individuals that are lost to follow-up; the only information is that they had "survived" until a time point previous to the end of the follow-up period. Left censoring applies to cases where the actual survival time is less than that observed (Collet, 2003).

Explanatory variables may be incorporated in a model for survival data, and the values considered will correspond with those at the origin time. However, in some studies, the value of certain explanatory variables can be determined at multiple times during the course of the experiment. Time-dependent covariates are those that may change in value over the course of the study.

As in the previous cases, the approach to survival analysis is based on probabilities, and the variable time has a probability distribution that determines the analysis model. A common way to describe this probability distribution is the hazard function, which quantifies the instantaneous risk that an event will occur at a particular time (Allison, 2004). Another central function is the survival function that is defined as the probability that an individual survives from the time origin to some point beyond a particular time (Collet, 2003).

A natural use of time analysis is to compare survival between two groups. Multiple methods can be used to quantify the extent between group differences. A simple model is the proportional hazards model that compares the hazard of an event at any time for individuals in one group (e.g., treatment) with the hazard of individuals in another group (e.g., control). The statistic estimated by this model is the hazard ratio. An important assumption of this model is that the hazards for the two groups are proportional at any time.

The Cox proportional hazards model was used to test the effect of stillbirths on dam survival (Bicalho et al., 2007). The analysis considered 13,608 cows; 2,142 individuals either died or were culled, and 84.2% of the enrolled cows were censored. The variables retained in the model were stillbirth occurrence, parity group, and calving difficulty. The hazard ratio of death/cull was 1.41 ($P < 0.001$) for cows that had stillbirths versus cows that had live calves; therefore the hazard rate of death/cull was 41% higher for cows that had stillbirths. A graphic representation of the results is also provided by the use of Kaplan–Meier analysis that results in a plot comparing dam survival in both groups (stillbirth vs. live calf) during the complete study period; the mean survival time was 255 and 270 days ($P < 0.001$) for cows that had stillborn or live calves, respectively.

The use of time-dependent covariates is illustrated by Gröhn et al. (1998) when modeling the effect of diseases on the risk of culling for different stages of lactation. By this methodology, the effect of covariates was demonstrated to change throughout the study period. Milk fever, retained fetal membranes, displaced abomasum, ketosis, ovarian cysts, and mastitis all raised the risk of culling at certain stages of lactation; ovarian cysts were protective against culling when conception status was

also considered. Mastitis, in particular, had an effect on culling throughout lactation.

A final example is provided by Hernandez et al. (2005a). When the risk of conception failure was analyzed, the hazard ratio for moderately lame and lame cows was 1.04 and 1.21 compared to a reference value of 1.0 for nonlame cows.

Epidemiological Concepts

Definitions

The analysis of health-related event occurrence requires the use of some epidemiological concepts. These mainly relate with the need of defining the adequate population and the time period to be considered. Definitions of commonly used terminology in epidemiological research may facilitate the utilization of these concepts and the interpretation of population studies.

Proportions are often estimated in dairy practice, corresponding to a number between 0.0 and 1.0 where the numerator is a subset of the denominator. Therefore, each individual in the denominator must be at risk of being in the numerator. This is the case of the number of pregnant cows over the total number of cows that received timed artificial insemination. On the other hand, when the numerator is not a subset of the denominator, the statistic corresponds to a *ratio.* This would be the case of the rate of abortions over calvings (both events are mutually exclusive). *Rates* are used when time needs to be considered. The value may be greater or equal to 0 and refers to the number of individuals in the at-risk group that experience the event during one time unit. Therefore, in this case, the denominator corresponds to the number of animal–time units at risk.

An example is 0.01 cases of ketosis per cow-month. Some other common examples are 21-day period pregnancy rate, annual abortion rate, or annual replacement rate.

The number of new events in a defined population within a specified period of time is defined as *incidence.* If the probability that an individual will have a particular condition is measured in a specific point in time, then the adequate term is prevalence. This parameter is commonly used in cross-sectional studies.

Case fatality rate is the cumulative incidence of death in the group of individuals that develop the disease over a time period. Similarly, mortality rate is the proportion of individuals in a population that die in a given period of time (usually a year), and it is usually expressed multiplied by a factor (100, 1000, etc.) subdivided into cause specific.

A commonly used term is risk, which is defined as the probability (usually quantified as an incidence rate or cumulative incidence proportion) that an individual will develop a given condition in a particular time period. According to this, risk ratio (relative risk) is the ratio of the probability of an event occurring in the exposed group versus a nonexposed group. The values range from 0 to infinity and indicate the strength of the association between the risk factor and a particular condition. Values larger than 1 indicate an increased risk, and values less than 1 indicate a protective effect for the factor. A good example can be found in the work of Gröhn et al. (1998) where the relative risk of being culled for a cow with a particular risk factor (parity, calving season, diseases, milk yield of the current lactation, and conception status) was presented. The results indicated that older cows were at a much higher risk of being culled (relative risk from 3.8 to 6.2 for parity ≥ 6 relative to parity 1). Once a cow had conceived again, her risk of culling dropped sharply (from 7.5 before conception to 1.0). Mastitis was an important risk factor throughout lactation with relative risks ranging from 1.1 to 7.3 when compared to cows without mastitis.

Considering that risk factor is an attribute or exposure that is positively or negatively associated with the occurrence of an event or condition, one way to measure the potential effect of a risk factor in an outcome is to estimate the attributable risk. This is the difference in the risk in the group exposed to a risk factor and the group not exposed to that risk factor.

Analyzing Diagnostic Tests

Two concepts are key in the evaluation of diagnostic tests: sensitivity and specificity. Sensitivity is the ability of a test to detect a certain condition; this is the proportion of affected (infected, diseased, etc.) individuals that test positive. On the other hand, specificity is the capacity of detecting the individuals that do not have the condition, that is, the proportion of nonaffected individuals that test negative (Martin et al., 1987). Naturally, the determination of sensitivity and specificity requires the knowledge of the real status of the individuals. This is possible in the presence of a gold standard test that always provides the right answer (Mckenna & Dohoo, 2006).

When the sensitivity and specificity are applied in the field with real populations, another concept, the predictive value of the test result, becomes important. The predictive value of a positive test is defined as the proportion of affected animals among those that tested positive. On the other hand, the predictive value of a negative test corresponds to the proportion of nonaffected animals among those that tested negative. Both predictive values are affected by the sensitivity and

specificity of the test and by the true prevalence of the condition (infection, disease) in each particular population.

In numerous cases, there are multiple diagnostic tests for the detection of a specific infection or disease. Determining the agreement among tests is useful before the election of the most convenient test to be applied. A commonly used measure of agreement is the kappa coefficient, which estimates the level of agreement beyond that expected by chance only. The coefficient ranges between 0 (no agreement) and 1 (perfect agreement) (Mckenna & Dohoo, 2006).

Sampling

There are two main reasons for taking a planned sample from a population. One is to describe the characteristics of a population as in the case of surveys. The second reason is to assess specific associations between events and/or factors in the population (Martin et al., 1987). In both cases, the objective of the process is to obtain a sample that is representative of the target population.

The method of choosing the sample is critical, and chance variability must be considered in the process (Freedman et al., 1998). However, in numerous studies, the details about the determination of the required sample size are not presented, and frequently, when the analysis does not indicate significant results, the conclusion states that a larger sample size could provide significance.

The sampling process may be very complex, but in general terms, a few key factors need to be considered. The first consideration is to determine the parameters to be estimated and the unit of concern (cow, herd, or region). When the aim is to estimate a mean or a percentage, the elements to be considered include population size, expected SD (mean) or expected prevalence (%), expected error, and confidence level (usually 95%). If the objective is to determine differences between means or percentages, the required information is the expected mean for groups 1 and 2 (proportions in the case of percentages), the expected SD, the confidence level, and power (commonly 80%).

In the case of sampling for detection of disease, the population size, the number of affected animals, and the confidence level will be needed. On the other hand, case-control studies require the proportion of controls per cases, the exposure rate for controls, the value for the ORs to be significant, the confidence level, and power. Finally, in the case of cohort studies, the percentage of nonexposed affected individuals, the relative risk to be considered significant, together with the confidence level, and power will be requested.

Statistical Analysis in Practical Settings

On-Farm Averages, Rates, Ratios, and Proportions

Some good examples of data summary can be found in the monthly DHIA herd summary report. Multiple averages are provided: daily milk average per cow on test day, rolling yearly herd milk average, fat and protein percent, and number of days to first service, among others. These values give an idea of the central tendency of the data but do not inform how spread the values are (range and SD).

Rates are used in multiple situations in dairy systems. Pregnancy rate is a commonly estimated statistic in dairies, and it has been defined as the product between two other rates: estrus detection rate and conception rate or as the number of cows eligible to become pregnant in a given time period (every 21 days) divided by the number of cows eligible to be inseminated and conceive (those detected in estrus and bred; Fetrow et al., 2007). Given that these are rates, the concept of time has to be included. In this case, the pregnancy rate will represent the number of individuals in the at-risk group (eligible cows) that conceive during one unit of time (21 days, 6 months, etc.). Rates are also very useful when analyzing disease incidence. Again the time unit should be defined mainly based on the frequency of the disease occurrence. A monthly interval may fit properly if diarrhea occurrence in calves is measured. On the other hand, a year interval may be appropriate to measure the abortion rate in a dairy.

A useful practice to avoid bias is keeping always in mind the population included in the denominator of any estimator. For example, when analyzing the conception rate at first service, consider that we are missing all the cows that were not bred. Similarly, the number of services per conception will include only the "successful" cows that were able to conceive. Checking this estimator does not inform anything about the population of cows that is performing the worst.

Statistical Process Control Charts

Control charts were developed with the aim of identifying and distinguishing between normal and abnormal variability (Reneau & Lukas, 2006) and consists of plots of observations (inputs or outcomes) over time with control limits that help interpretation. Control charts can also be used to determine whether or not the performance of the process is improving, staying the same, or getting worse over time. Control charts display the level of normal, random variation in the data and reveal the observations that indicate real change and help

identify factors that can lead to increased productivity and profit. Any type of observations can be plotted on control charts, whether the observations are continuous (pounds of milk, somatic cell counts, body weights), discrete (number of sick animals), or both (pregnancy rates). In general, the *x*-axis expresses the time while the *y*-axis displays the values of the parameter being measured. Control charts can be created by the user, with stand-alone SPC software (Reneau & Lukas, 2006) or using add-ons such as Microsoft Excel (Microsoft Corp., Redmond, WA).

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22

Dairy Records Analysis and Evaluation of Performance

Michael W. Overton

Abstract

A key component of animal health and management is the monitoring and evaluation of the overall productivity of the herd including specific health outcomes, level of productivity, opportunities to improve cow comfort and animal well-being, and feeding management. Monitoring involves the routine and systematic collection and evaluation of information. The purpose of monitoring dairy performance through records analysis is to detect change within the production system. In order to accurately detect real change, a structured approach should be used, paying careful attention to issues such as lag, momentum, variation and bias. Veterinarians need to improve their approach and evaluation of dairy records in order to better identify changes in performance and to improve animal health and farm profitability. This chapter will describe some of the concepts, approaches, and cautions regarding the evaluation of productivity with specific attention given to the monitoring of reproductive performance, transition cow performance, milk production, mastitis, and young stock performance.

Introduction

Dairy animal health and management services typically center on routine farm visits that incorporate traditional practice activities such as individual animal diagnostics and treatment as well as "herd health" activities including reproductive examinations, management and treatment protocol creation and review, preventive health programs including vaccinations, and herd health monitoring. According to Brand and Guard (Brand & Guard, 1996), the primary objectives of herd-based services are the optimization of

1. The health status of the herd by prevention of health, productive, and reproductive problems,
2. The productivity of the herd by improving management practices,
3. The production process in relation to animal welfare and ecological quality of the environment and the maintenance of a sustainable dairy industry,
4. The quality and safety of dairy and meat products, and
5. The overall profitability of the dairy enterprise system.

A key component of the animal health and management duties described above is the monitoring and evaluation of the overall productivity of the herd including specific health outcomes, level of productivity, opportunities to improve cow comfort and animal well-being, and feeding management. The primary source of income on nearly all dairies is the production and sale of milk. Consequently, special attention should be placed on the proper evaluation of reproduction and transition cow performance, since these two areas have such a large impact on the level of milk produced on each individual dairy. The following chapter will describe some of the concepts, approaches, and concerns with evaluating productivity in the areas of reproductive performance, transition cow

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issues, milk production, mastitis, and young stock performance, but specific attention will be devoted to the monitoring of reproductive performance. Due to the flexibility afforded by the system and due to its worldwide popularity and use, the DairyComp 305 (Valley Agricultural Software©, Tulare, CA; www.vas.com/dairycomp.jsp) record system will be the primary system used for examples throughout much of the chapter.

Why Monitor?

Monitoring is the regular observation and recording of activities, events, and yields that occur for the purposes of observing and evaluating the degree of change, intended or unintended, positive or negative, within a system. It should include a systematic approach to data collection, evaluation, and provision of feedback about the changes detected. The objectives of monitoring include: (1) to recognize "normal" performance, (2) to test the impact of intentional change in some area of management or performance, (3) to discover unintended drifts or declines in procedures or performance, and (4) to determine potential causes of abnormal performance. However, before getting into specific monitors, reports, or interpretation, there are some general concepts, concerns, and terminology that must be considered.

Goals are target levels of performance toward which producers are trying to achieve and are typically related to profitability. For instance, a farm might have a goal of higher milk production, better reproductive performance, or lower somatic cell counts. Metrics are any type of measurement or set of measurements that quantify results and are used to gauge some quantifiable component of dairy performance, that is, is the herd meeting its goals. Metrics that are monitored in dairy production are typically numbers that represent some type of process and are always important in achieving a goal, but are not synonymous with the goal themselves. It is great to have goals, but it is rarely a good idea to use the goal as a monitor. An example might be the average age-at-freshening of replacement heifers. If the average age has been 27 months, it might be a good goal to lower this age by a few months. Age-at-freshening is an appropriate goal, but a horrible monitor since it is the result of many processes that are involved in achievement of the goal such as appropriate feeding, housing, vaccination, and breeding. The process of monitoring involves the routine and systematic collection and evaluation of information (monitoring parameters) from a dairy in an attempt to detect change in the process. In order to do this, it is critical to monitor as close to the process(es) as possible, as opposed to measuring the goal. Appropriate breeding-related metrics that should be monitored in an attempt to reduce the age-at-freshening for heifers might include age at first service, insemination risk, and conception risk. The focus for performance analysis should be on process monitoring versus simply relying on outcome monitoring.

Monitoring is vitally important to improving performance of a dairy but mistakes in monitoring and in interpretation of results are often made. "Normal," "change," and "abnormal" are elusive and frequently problematic concepts because these issues are often thought of as only point estimates while biological systems such as cows within dairies often fail to perform as homogenous groups. A number of problems plague this approach to monitoring and analyzing data and can lead to inaccurate conclusions, resulting in delays in action or alternatively, taking action when problems do not truly exist. These issues will be discussed below and have been adapted in part from previous work by S.W. Eicker (pers. comm.), S. Stewart (pers. comm.), W.M. Sischo (pers. comm.), and other key individuals in the field of performance monitoring (Fetrow et al., 1994; Farin & Slenning, 2001).

Adage 1: Never Believe a "Number" Without Validating the Data Collection Process

Often, when presented with information from dairies, the first reaction is to proceed to evaluate how well the herd is performing. However, the first step should be to ensure the quality of the data is satisfactory in order to answer the questions being posed. Inevitably, minor errors such as keystroke errors with an individual cow event recording may occur even with the best of intentions. Fortunately, this type of error is relatively minor from a herd perspective. However, a more common and potentially more egregious error is not having complete information either because historical records are missing (culled cows are missing, for example) or because the input of data into the computer-based record system is not up to date.

Tools for data checking include identifying the minimum and maximum values, total number of values (n), and the quartiles, and plotting the distribution of the values. The minimum and maximum values should be within the expected range and for data that is believed to be normally distributed, the median should be near midpoint of the range and similar to the mean for the data. Many times, simply examining a scatter plot or histogram of the data will reveal the presence of extreme outliers, demonstrate missing data points, or confirm the distributional shape of the data under consideration.

Another tool for data checking that is unique to DairyComp305 is the "Guide" feature. Entering "Guide" at the command prompt will bring up a set of menu tabs

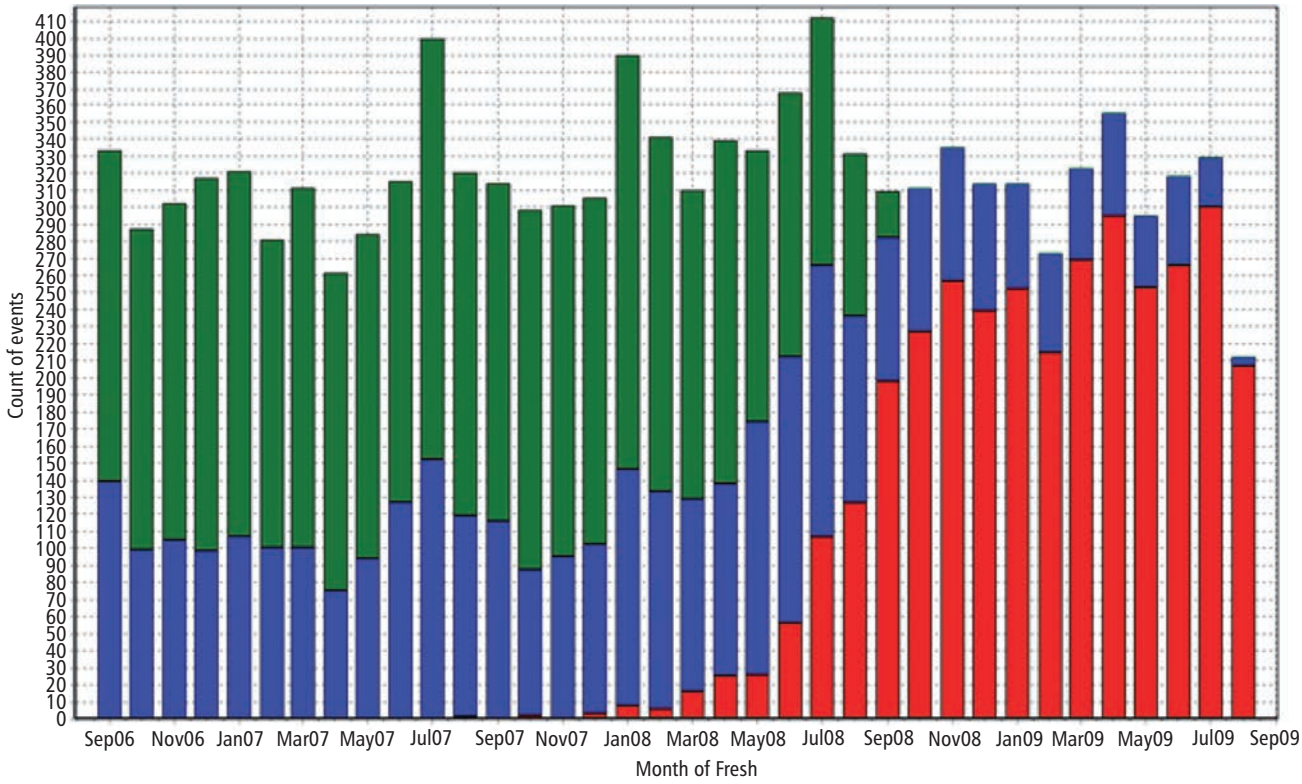

Figure 22.1. A histogram of the number of calvings for a herd across time. The red bars represent current, live cows; the blue bars represent culled cows that are still in the active cow record database; and the green bars represent culled cows whose records have been moved into the archive files from the active cow file. The *y*-axis is a count of cows and the *x*-axis is the month of calving.

with each containing a variety of reports. Under the "Data Checks" section, there are a variety of reports designed to help determine if the data appear reasonable and complete. These data checks are not calculating specific variables such as mean and median, but rather are serving as a quick visual assessment as to the apparent completeness of the records system. Examples of questions that might be asked as a form of "data checks" include

1. Are current lactation, historical lactation and departed cow records available? In Figure 22.1, a frequency histogram is shown that reflects the calving patterns for a herd across a 3-year period of time. While there is some variation month to month, the overall pattern indicates that the herd typically calved approximately 310 animals per month across the 3-year period. However, if the archive records were not present, one possible conclusion might be that the herd had more than doubled the number of animals calving per month over the 3-year period.
2. Are current and historical reproductive outcome records available? In Figure 22.2, the reproductive events, as recorded each month, as shown for a 3-year period in a large dairy herd. Across time, there is a fairly consistent pattern of pregnancy production evident in this herd, and it is likely that sufficient historical records are present to analyze reproductive trends over the most recent 3 years. Based on the information observed in Figures 22.1 and 22.2, it appears most likely that there is sufficient historical and archived information to examine reproductive performance to move forward with the data analyses.

Adage 2: Beware of the Impact of Lag on Outcomes

Lag refers to the elapsed time between when an event occurs and when it is measured. Lag is inherent in many reproductive parameters such as conception risk because of the necessary wait from breeding until the outcome can be determined by either a return to estrus or by pregnancy evaluation. However, the lag for conception risk is only about 40 +/−20 days depending on the method of outcome determination and frequency of visits to the farm. In comparison, calving interval (defined as the total interval from one calving to the next for animals that successfully calved at least twice) has a much longer lag associated with it. In order for a cow to have an actual calving interval recorded, she must calve,

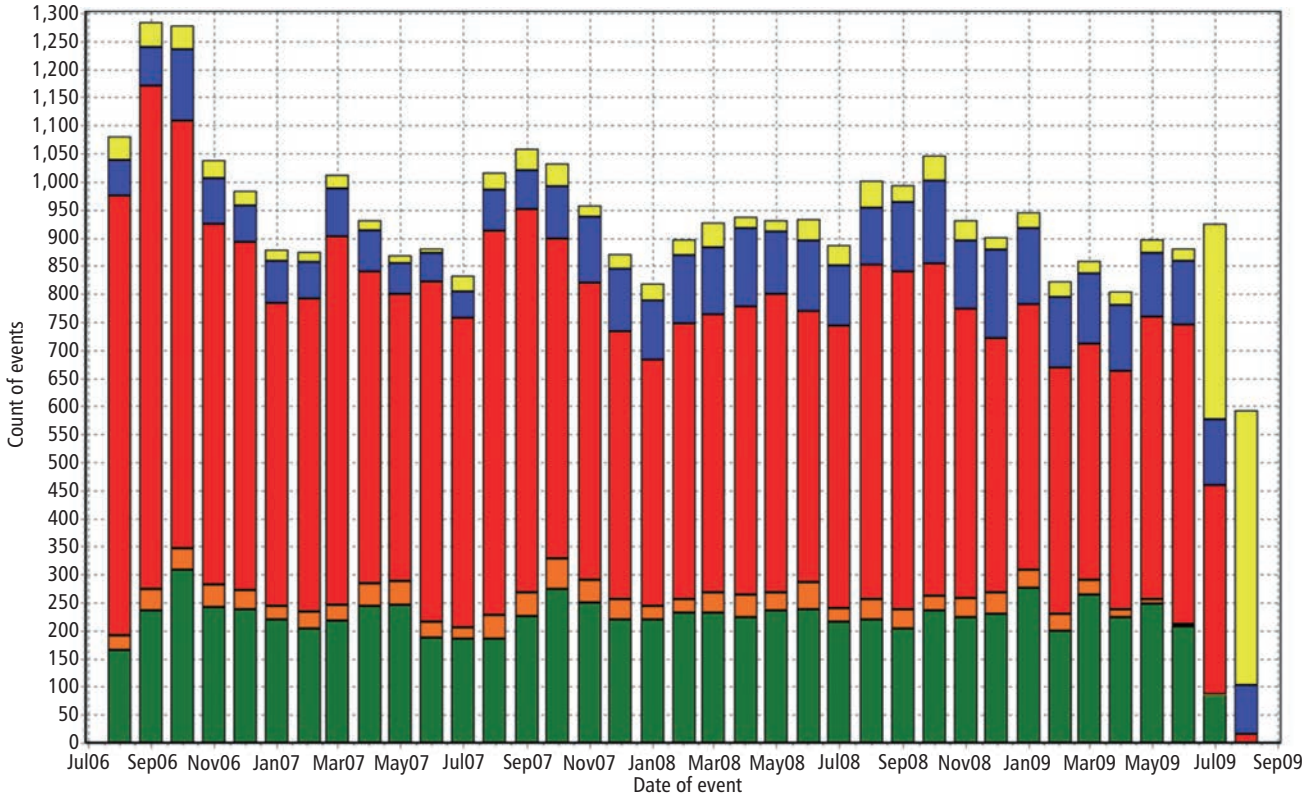

Figure 22.2. Reproductive events across a three year period for a large dairy herd. The green bars represent pregnancies; the orange bars are abortions; the red bars are cows declared not pregnant; the blue represents cows that were reinseminated since the previous insemination; and the yellow bars are animals with unknown status. The *y*-axis is a count of cows and the *x*-axis is the month of calving.

conceive again, maintain the pregnancy, avoid being culled, and then calve again. This results in a lag of 10–20 months or more, depending on how quickly a cow becomes pregnant. While some may argue that a lower calving interval is a reasonable goal, it is a very poor monitoring parameter for reproductive management because of the problems created by the inherent lag that is present.

Adage 3: Beware of the Impact of Momentum on Outcomes

Momentum refers to the dampening or buffering effect that results from excessive influence of events from the distant past on current performance; that is, recent changes may be obscured by the weight of historical performance. As a consequence, mistakes may be made in interpretation of performance in either direction. For example, if a herd is using the annual actual calving interval as their reproductive monitor, the herd may not realize that progress is being made in reproductive efficiency if the rolling average calving interval is the metric being evaluated due to the severe dampening effect of months of previous poor performance. Conversely, reproductive efficiency may be declining rapidly, but due to a combination of the severe lag and large impact of momentum, actual calving interval may still look respectable. The most common example in dairy record systems of momentum is rolling herd average (RHA). While RHA is a reasonable estimate of the overall efficiency of the herd across time, it is a poor monitor to use to assess changes in recent milk production since this metric contains not only the current month's numbers but also data from the previous 11 months as well. The result is a smoothed, rolling average that is slow to reflect change, either positive or negative, in the area of milk production.

Adage 4: Beware of Bias

Bias is a systematic error in the collection, analysis, or interpretation of data that can lead to incorrect conclusions. Or, to put it in more simple terms, bias is the incorrect inclusion or exclusion of cows from the parameter calculation. Dairy production records contain many variables that are rife with bias. For example, consider the commonly used term "days open." Typically, days open is defined as the number of days from calving until

conception. While there is nothing inherently wrong with the concept of days open for the cows that actually became pregnant, the use of days open as a herd metric to evaluate reproductive performance is very problematic because it only conveys information for a portion of the total herd; that is, it is a biased metric that only reports the results for the successful cows. No information is gained for cows that left the herd without becoming pregnant, and there is no indication of what percent of cows failed to become pregnant.

Days open is a terrible measure of reproductive performance for another reason. In most herds, the average days open for the highest producing cows is 30–100 days longer than for cows of average to below average milk production. As a consequence, many people feel that high-producing cows have a more difficult time becoming pregnant. However, most forget that lower producing animals get culled earlier than high-producing cows, and they will receive fewer days at risk to become pregnant. Since cows that are culled from the herd without becoming pregnant do not contribute to the days open, a biased estimate results that leads people to conclude that high producers are less fertile.

Taking this issue a bit further, consider once again the use of calving interval. This particular metric is even more biased than days open as it reflects cows that not only became pregnant, but maintained the pregnancy, and calved again. Furthermore, current first lactation animals are automatically excluded from consideration and older animals are included, but only after calving again. There is no information regarding animals that failed to become pregnant, failed to maintain a pregnancy, or that were culled from the herd. Excluding subpopulations such as these may make the numbers look better but do not adequately evaluate the herd's true performance and thus are biased metrics.

Bias can also be introduced into the evaluation if cow records are incomplete or if assumptions are made regarding pregnancy outcome. Also, some record systems still use nonreturn information for the purposes of calculating reproductive efficiency estimates. Cows with a recorded breeding but no follow-up pregnancy determination or additional inseminations may be assumed pregnant after a specified period of time. In these herds, the apparent reproductive efficiency as reported on the Dairy Herd Information Association (DHIA) summary sheet may appear to be substantially higher than reality.

Another important source of bias in dairy records concerns the use of bulls. In many DHIA systems, services per conception (SPC) are still reported and are often used for making management decisions about reproductive performance. However, the inclusion of bull-bred cows in this calculation tends to bias the results so that they are artificially low. Consider the following scenarios:

a. A herd that utilizes both artificial insemination (AI) and bull breeding, but moves all cows to the bull following their second service. Cows in this herd that become pregnant have only a few possibilities: (1) they conceive to first AI and have 1 SPC; (2) they conceive to the second AI service and have 2 SPC; (3) they conceive to the bull after two failed AI attempts and have 3 SPC; or (4) they fail to conceive and are culled. In this case, no cow would ever have an SPC greater than three since they are moved to the bull after the second AI.
b. A herd utilizes both AI and bull breeding, but moves many cows to the bull without ever receiving an AI service. Cows in this herd will also have a much lower SPC than the previous herd (assuming equal effectiveness of the AI program) since cows that are moved to the bull pen without an AI service that become pregnant by the bull will always have an SPC of 1 even if the bull serviced the cow 20 times prior to conception.
c. A herd that utilizes all AI. This herd could do a better job with first and second service conception risk and still have a much higher overall SPC (and therefore, a much lower overall conception risk) simply because cows are serviced by AI more times and this service information was recorded.

Adage 5: Beware of Means and the Impact of Variation

Dairy herd records contain many different parameters based on the calculation of a mean or average. Average SPC, average days-to-first-service, average days-in-milk, and average linear somatic cell count score (LSCC) are all commonly cited metrics. However, a mean is a parametric statistic that is used to describe the central tendency for continuous data that assume a normal distribution. With the possible exception of LSCC, which is a log-transformed number designed to more closely mimic a normal distribution, none of these distributions resembles a normal distribution, and the mean may not actually reflect the true central tendency.

Consider the two graphs of days-to-first insemination for two different herds as shown in Figures 22.3 and 22.4. In Figure 22.3, herd "A," which has an average days-to-first-service of 60, relies on estrus detection only for first insemination, and there is a skewed distribution of days-to-first-service due to estrus detection inefficiency or failure of cows to cycle in a timely manner. The mean does not really represent the true central tendency as 70% of the first inseminations have occurred by 60 days

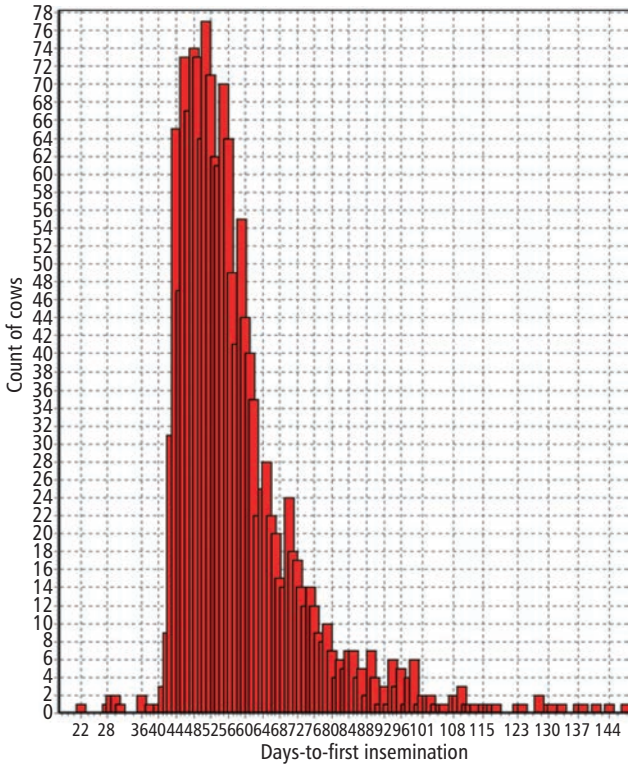

Figure 22.3. A frequency histogram of days-to-first insemination for Herd "A." In this herd, the average days-to-first servic = 60.

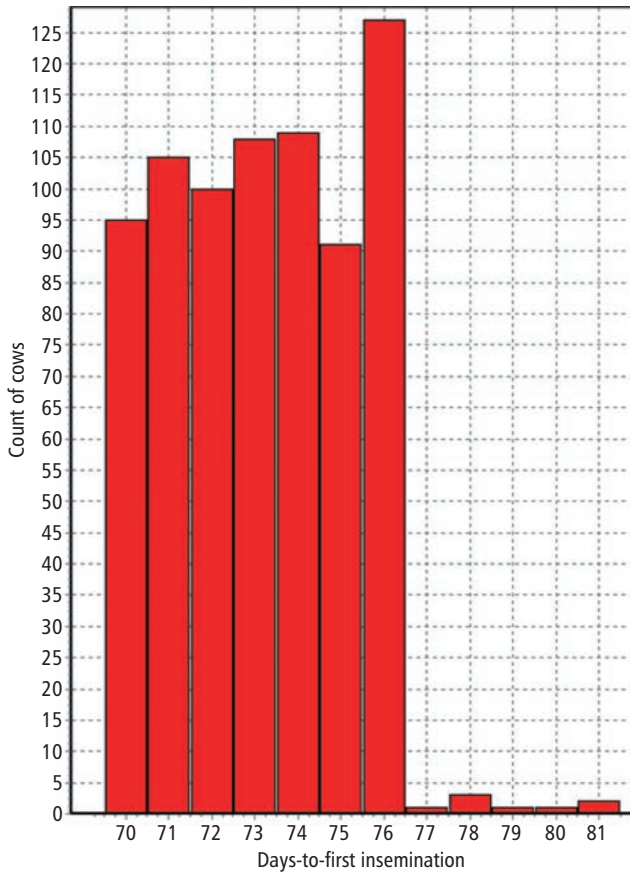

Figure 22.4. A frequency histogram of days-to-first insemination for Herd "B." In this herd, the average days-to-first insemination = 73.

in milk. The long tail off to the right side skews the data and pulls the mean away from the true midpoint.

For comparison, consider herd "B" as shown in Figure 22.4. This herd's average days-to-first service is 73 and approximately 50% of the first services have occurred by day 73. Also, notice the very small spread of the data that is common in herds that maintain a high level of compliance with a timed AI program for first service. In this case, knowing that the herd's average days-to-first service is 73 gives a much better idea of how a typical cow in this herd is performing.

Means alone, however, do nothing to describe the spread of the distribution and two herds could have the same approximate mean for a metric such as days-in-milk or days-to-first service, but due to different distributional shapes and different ranges of variation, far different conclusions regarding performance could be reached depending on how deeply the real data is examined. Variability is the measure of data dispersion within a distribution and explains whether data are clustered or widely distributed. In normal distributions, the standard deviation (SD) measures the variability of observations around the mean, with one SD on either side of the mean capturing about 66% of the data and two SDs on either side of the mean capturing about 95% of the data. In essence, the SD describes the amount of variation present and reveals the level of confidence afforded by the mean to describe a typical individual within the population.

Variability appears in two distinct forms: random variation and special cause (W.M. Sischo, pers. comm.). From a statistical perspective, random variation is important because this is the inherent "noise" in the system that must be accounted for when trying to determine if management is making progress toward improvement. Special cause variation is associated with a change in the system and is preventable and manageable, but must be identified and accounted for within the calculation of parameters. For example, examine the scatter plot of days-to-first insemination for herd "C." This herd made a management decision (see the black arrow within Fig. 22.5) to change their approach to delivering first service. In 2006, herd "C" used a modified Presynch-Ovsynch (Thatcher et al., 2002) timed AI protocol with a 14-day interval between the end of the presynchronization injections and the start of Ovsynch. Throughout the breeding management program, cows detected in estrus were inseminated, and no other injections were administered. In January, 2007, herd "C" modified the program

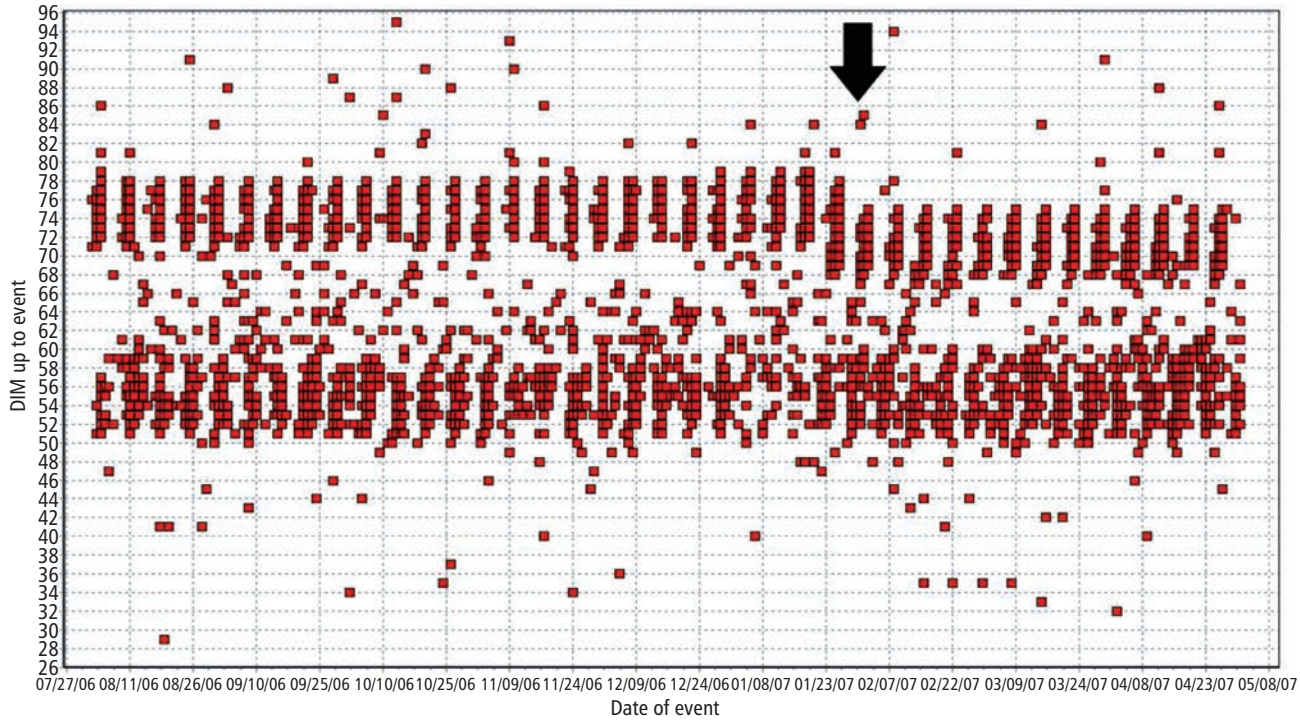

Figure 22.5. A scatter plot of days-to-first insemination for herd "C". The *x*-axis reflects the date of the event (first insemination) and the *y*-axis shows the days in milk up to this event. Each small square represents an individual cow.

by moving from a 14-day to an 11-day interval between Presynch and Ovsynch. In this herd's case, following the average days-to-first insemination would have demonstrated a small change in average days-to-first insemination (from 67 to 64) that might suggest that the percent of cows inseminated based on estrus detection had increased, but further evaluation would demonstrate that a management change had occurred.

Table 22.1. Frequency distribution of animals by category for a large dairy

Category	Count	Relative frequency
Wet Calves	258	4%
Heifers	2901	44%
Cows	3355	52%

Adage 6: Beware of Data Type

Data can generally be classified into one of two large categories: qualitative or quantitative. Qualitative data are also called categorical or descriptive data and can be split into subtypes that include nominal (categories that are named and have no inherent ranking such as breed, gender, color, and production status) or ordinal (categories that can be ordered such as small, medium, large or calf, heifer, cow). Qualitative data are analyzed by counting events or occurrences and are often displayed or summarized by the use of frequency distributions as shown in Table 22.1.

Quantitative data, on the other hand, are numerical information that can actually be counted or measured. This type of data can be subdivided into discrete and continuous data. Discrete data are typically counts or values that contain specific gaps like body condition score or parity, but may also include categories of continuous data such as percent of cows with linear score 0–3 and percent of cows with dry period lengths of 40–70 days.

Continuous data are measurements for which all values are theoretically possible (barring some upper or lower boundary) and for which the interval between values is technically infinite such as height of heifers at breeding, pounds of peak milk in mature cows, and temperature. Continuous quantitative data are usually summarized by measures of central tendency such as means and by measures of dispersion like SD.

The analysis of qualitative and discrete quantitative data usually involves the calculation of risks, rates, ratios, or proportions. Ratios are a comparison of two numbers or populations such as the ratio of bull to heifer calves or the ratio of first lactation to mature cows within a herd. The hallmark of a ratio is that the numerator and

denominator are mutually exclusive and are not bounded from 0 to 1. A proportion, on the other hand, is a number that ranges from 0 to 1 if expressed as a probability, or between 0% and 100% if expressed as a percentage, and is a measure of frequency of some condition. In a proportion, the numerator is a subset of the denominator. For example, to characterize how many cows in the lactating herd are parity = 1, a proportion could be used:

$$\frac{\text{The number of first parity cows in lactation}}{\text{The total number of cows in lactation}} = \frac{1085}{3100} = 35\%$$

Risks are similar to proportions in that the numerator is included in the denominator but a time duration is specified or implied. For example, the risk of a displaced abomasum in cows that calved between 30 and 60 days ago could be calculated as follows:

$$\frac{\text{The number that calved 30–60 days ago and diagnosed with displaced abomasum}}{\text{The total number of cows that calved between 30 and 60 days ago}} = \frac{8}{245} = 3\%$$

One problem with risk is that many people assume that a risk implies a negative outcome. However, this is not true. For example, a very commonly used metric for reproductive purposes is conception rate, defined as the number of animals that conceived divided by the number inseminated and now known to be either pregnant or not within some time period. Strictly speaking, conception rate should actually be called conception risk, and there are very few instances where having a higher proportion of animals conceive would be considered a bad outcome.

"Rate" is a very much misunderstood term. Epidemiologically, rate refers to the speed at which an event occurs and is calculated by dividing the number of *new* events by some population time at risk. For example, life insurance companies are very interested in determining the different mortality rates across time for people within various population strata so that they can know how much to charge for life insurance. Companies can calculate this mortality rate by way of an incidence density rate and by using life table analysis (or survival analysis). For an incidence density rate, the number of deaths for a given population is divided by the total number of days at risk or years at risk until death occurs. Survival analysis is a very similar concept but is displayed in graphical form. Within each period of time, either on a daily basis, monthly basis, annual basis, or some other time interval, individuals within the population have some estimated risk of experiencing the event (death). Within that given period of time, the probability of a person dying is a risk (numbers that die/numbers at risk of dying), but when the entire population is examined across the generational time, the true "rate" or speed at which the population is dying can be determined.

Table 22.2. Two distinct scenarios that depict the reproductive performance for two hypothetical populations of 100 heifers each across four possible breeding cycles

Cycle #	#Eligible	# Pregnancies	Rate
Scenario 1[1]			
1	100	55	55%
2	45	10	22%
3	35	7	20%
4	28	6	21%
Total	208	78	38%
Scenario 2[2]			
1	100	6	6%
2	94	7	7%
3	87	10	11%
4	77	55	71%
Total	358	78	22%

[1] Pregnancy rate through 4 cycles = 38%; cumulative pregnancy risk = 78%; ratio pregnant : nonpregnant = 78:22.
[2] Pregnancy rate through 4 cycles = 22%; cumulative pregnancy risk = 78%; ratio pregnant : nonpregnant = 78:22.

In dairy production medicine, outside of a research setting, there are very few instances where a true rate is utilized and more often than not, the unit of interest is simply the risk of a disease or event occurring within a population. A very confusing dairy metric that at times can be either a rate or a risk, depending upon the calculation approach taken and the time frame under consideration, is pregnancy rate (or pregnancy risk). To illustrate this concept, refer to Table 22.2, in which two distinct scenarios of reproductive performance across four possible breeding cycles are shown. In each hypothetical scenario, 100 nonpregnant animals are started through a breeding period at the same time and potentially remain eligible for breeding through four 21-day cycles with no culling and no new animals added to the population. In scenario 1, breeding performance starts very well in the first cycle and declines somewhat over the remaining three cycles. In the second scenario, the same total number of pregnancies is created, but in reverse order to the first scenario.

In both cases, the cumulative pregnancy risk (or cumulative proportion pregnant) over four breeding

cycles is 78% (78 pregnant cows/100 cows at risk) and the ratio of pregnant to nonpregnant animals is 78:22. Within each cycle number, the pregnancy risk, calculated by dividing the total number of pregnancies by the total number of cows at risk within that cycle, varies from 20% to 55% for scenario 1 and from 6% to 71% for scenario 2. However, the pregnancy rate, calculated by dividing the total number of pregnancies produced by the total number of cow cycles at risk over the four total cycles is much higher in scenario 1 (38%) than in scenario 2 (22%). In this simplistic example, it is quite clear that the metric that conveys the most information about how successfully the herd generated pregnancies is pregnancy rate. Scenario 1 has the higher pregnancy rate and created more pregnancies earlier in the breeding window than scenario 2 although the net number of pregnancies is the same over the cumulative time frame. In general, calculating a true rate gives a clearer picture of the success or failure of a system since it considers population time at risk and not simply the initial population under consideration. However, in evaluating dairy reproduction in a commercial setting, the question under consideration is not how fast a specific group of cows has gotten pregnant over their lactational time at risk, but rather, how efficiently is the herd producing pregnancies. Thus, records are examined frequently on a 21-day calendar basis so that the most recent breeding information can be examined from a herd perspective. In this case, it would be appropriate to use either term, pregnancy rate or pregnancy risk. Although the two terms are not exactly the same, they will be used interchangeably and abbreviated as PR throughout the remainder of this chapter. There will be more discussion on PR later in this chapter.

Adage 7: Beware of Sample Size when Considering Success or Failure of a Management Intervention

Monitoring is a useful concept to help determine whether performance is improving, declining, or staying the same. Unfortunately, important decisions about the impact of some management change or technician are often made without adequate numbers to correctly answer the question under consideration. Consider the issues of conception risk by technician. Dairy "X" hired a new person (Joe) to help manage the reproductive program on the dairy 6 months ago and now is wondering if they made the right decision. In comparing the conception risks (CR) for Joe and Bob (the previous breeder), they noticed that Joe's CR is only 28% as compared to Bob's 33% CR.

Technician	Conception Risk	#Preg	#Open	SPC	95% CI
Joe	28%	186	473	3.5	25%–32%
Bob	33%	125	256	3	28%–38%

Upon examination of the CRs of the two individuals, it is apparent that there are numerical differences between the two breeders. However, the 95% confidence intervals (CIs) overlap, indicating that there is no statistically significant difference between the two inseminators. At this point, the owner could look only at the crude CR and decide that Joe needs to go and he needs to try and rehire Bob. However, in Joe's defense, there is not a significant difference between the two in performance and he and Bob were likely breeding different populations of animals during different seasons of the year. Bob may have had more first lactation animals that were more fertile or some other explanation may exist as to why the populations of animal the two were breeding were somehow different. Often, the records can be examined further and additional strata can be created for these different factors, but with each new stratum examined, the sample size gets smaller, and the ability to detect true differences becomes less likely.

When working with herd data, waiting until obtaining complete statistical evidence is present to support a decision to make a management change is often not practical, especially in small- to medium-sized herds. A small herd may have to wait 5 years or more before accumulating enough numbers to compare outcomes such as conception risk, and clearly, this length of delay is excessive. When confronted with decisions such as this, weighing the potential type I versus type II error cost, that is, which mistake is more costly—assuming that a problem exists and making a change (when it may not really be a problem) or taking a chance that everything is OK and continuing with status quo—is likely the best approach.

Evaluating Reproductive Performance

The general conceptual goal of most dairies is to optimize milk production per day of life for its cows. Cows must calve at regular intervals to maintain herd size and to optimize milk production. Generally, the longer a cow spends in lactation, the lower the milk per day of lactation. Typically, an average cow declines in milk production by approximately 0.1–0.2 lb (0.05–0.09 kg) per day once past peak milk production, excluding first lactation animals that often decline by half of this amount. As such, reproductive management of a dairy herd is critical

to the overall profitability of a herd due to its link to the production of new pregnancies that lead to fresh cows, the initiation of a new lactation, and a reduction in average days-in-milk for the herd. Delayed conception can lead to lower total milk production, fewer offspring produced, and a greater risk of premature removal from the herd (culling) as a result of a failure to become pregnant. The goal of monitoring reproductive performance is to assess the efficiency of the herd in converting nonpregnant animals into pregnant animals.

Various approaches for monitoring and improving reproductive performance have been described (Brand & Guard, 1996; Farin & Slenning, 2001; Fetrow et al., 2007). However, two individuals, Dr. Steve Eicker and Dr. Steven Stewart, both with Valley Agricultural Software, have probably done more to shape the current approaches to reproductive monitoring than any other. Much of the following material regarding the monitoring of reproduction in today's modern dairy herd has been adapted from their work in this area and is featured in the DairyComp305 software program.

Today's modern computer programs have the ability to create many different graphs and figures. Unfortunately, many people start by looking at graphs or canned reports and try to determine what these reports are telling them. Often, the population at risk is not defined, the time at risk is not specified, or the metric reported does not necessarily reveal the true condition of the system. The correct approach is to first ask an appropriate question, preferably related to the process rather than the outcome, and then find the data that answer the question posed. With this approach, the operator must first think of the question (i.e., the problem) and look to find answers using specific ranges in time. When evaluating reproduction, there are a few key questions that should serve as the basis for investigation, with additional questions developed as the investigation continues, depending on the initial outcomes.

1. **Are there sufficient records present and in the necessary form to answer the questions posed about herd performance? Are the records up to date?**

   Incomplete records usually lead to incorrect conclusions regarding performance. As an example, consider the herd that requested consultative services to improve performance and profitability. Upon examination of the herd records, the conclusion initially reached was that the herd only had approximately 22% of the herd pregnant and was running a PR (natural service sires) of 6%. Upon further review, it was discovered that pregnancy evaluation results had not been entered into the record system for the previous 3–4 months. After entering the data, the proportion pregnant rose to about 40%, not as high as desired, but much better than previously thought.

   a. Are historical records (including cows that have been culled or calved back into the herd again) spanning at least the past year present and complete?
   b. Are the breeding, culling, and calving inputs up to date as well as the most recent pregnancy diagnoses?
   c. Are pens or codes related to reproductive management approach clearly defined as AI or natural service?

   Some dairy records programs, such as DairyComp305, utilize a pen designation to distinguish AI versus natural service cows. If the pen designations are not accurately labeled in the software, PR calculations will not be performed accurately by breeding management option. For example, if the performance question posed is "How is the AI program performing?", but if the pens are not labeled properly, an incorrect conclusion is likely to be reached. Other programs such as PCDart use a cow-level code to indicate whether a cow's breeding information is from AI or natural service sires. If the herd is not using a "T" code (turned with bull, within the PCDart record system only), the natural service evaluation component of the evaluation will not be accurate.

2. **Is the herd producing enough pregnancies in a timely and efficient manner?**

   Timely and efficient production of a sufficient number of pregnancies to either maintain or grow the herd is the goal, but there are different approaches to evaluating success or failure, depending upon the perspective taken. One of the most common methods for evaluating the question, "Is the herd producing a sufficient number of pregnancies to at least maintain herd size?" is commonly referred to as the *pregnancy-hard-count*. Nonseasonal herds that are stable in size and not trying to expand should calve approximately 10% of the average milking herd per month. For example, if a herd has 1000 milking cows (not including dry), it should calve about 100 animals per month. Based upon projected annual culling risks, about 30%–35% of calvings should come from heifers calving into the herd for the first time and the remaining 65%–70% of the future calvings need to come from pregnancies generated and retained in the milking herd as shown in Table 22.3. Notice in Table 22.3 that the total number of pregnancies that should be produced is higher than the final number of calvings desired. The difference is due to the expected culling and pregnancy losses that are inevitable across

Table 22.3. An illustration of one approach to estimating monthly pregnancy needs for a dairy using a pregnancy hard count

Pregnancy hard count calculator		
Assumptions:		
# Milking	1000	
Annual culling risk	33%	
	Cows	Heifers
% of new pregnancies:	67%	33%
Abortion risk	12%	2%
Other culling losses	2%	1%
Total losses:	14%	3%
# New pregnancies per month (steady state calving):		
	Cows	Heifers
#/Month	76	34
% of lactating herd/month	7.6%	3.4%

time. These expected losses vary based upon when pregnancy is diagnosed. Although this tool has been used by many as a monitor or as a motivational tool for employees, it has so many flaws that its continued use is strongly discouraged.

One critical fault with this tool is that it does not consider the population at risk of becoming pregnant. Many herds experience major fluctuations in calvings per month due to heat stress, purchased replacements entering the system, impacts from past abortion storms, or simply accumulations of animals due to poor reproductive performance. Consequently, the population at risk for each period of time is inconsistent. Looking across time, even if the PR is relatively consistent, the pregnancy hard count may have tremendous variation due to the changing population at risk. Also, over time, a herd can accumulate a large number of cows that are later in lactation but still not pregnant. The population of animals at risk of becoming pregnant increases, but despite poor overall reproductive efficiency, the pregnancy hard count may appear to stabilize and it may seem as though the herd's reproductive problems have been resolved. However, due to the poor reproductive efficiency, as assessed by PR, which led to the accumulation of many late lactation, nonpregnant animals persists.

When striving to meet some theoretical target for pregnancies generated per month, some consultants have made the suggestion that given a herd's conception risk, the herd needs to breed "X" number of cows per month. While mathematically, this approach may make sense, biologically, it can be a disaster. Merely telling a breeding technician that 110 cows need to be inseminated this month in order to generate 35 new pregnancies does nothing to improve reproductive efficiency. This approach ignores the population at risk, potentially leads to a reduction in conception risk, increases the likelihood that the inseminator iatrogenically causes an increase in late embryonic death and abortion, and likely results in a decrease in overall reproductive efficiency.

Also, pregnancy hard count is an outcome and merely monitoring an outcome without regard to the critical processes driving it is a poor way to evaluate reproductive performance. As a consequence of each of the aforementioned issues, pregnancy hard count should not be used as monitor of reproductive performance.

One place that pregnancy hard count (or, perhaps the better term would be pregnancy inventory) might have some utility is in the area of forecasting calving patterns and transition management needs. Shown in Figure 22.6 is a pregnancy inventory graph for a herd milking 1600 cows, displayed by week of the year the cows are due to calve. The orange, red, blue, and green columns represent the number of heifers, first lactation cows, second lactation cows, and third and greater lactation cows, respectively, that are due to calve for each corresponding week indicated on the "X" axis. Since no information regarding the population at risk is known, no valid conclusions can be made regarding the reproductive efficiency of the herd, but this information can be used to forecast projected calving patterns. Given the information presented in Figure 22.6, the herd should plan ahead in order to adequately handle the larger than normal number of pregnancies due during August and October. When a slug of pregnancies moves through the system, the transition facilities can easily become overcrowded and overwhelmed, leading to compromised fresh cow health, greater early lactation culling, reduced milk production, and compromised future reproductive performance.

To summarize, PR accounts for the population at risk, but pregnancy hard count does not. Thus, PR gives credit to pregnancies that occur earlier in lactation, but pregnancy hard count does not. There is a large economic difference between getting cows pregnant at 80–120 days in milk, versus 150–180 days in milk (Overton, 2001, 2009). Therefore, PR should be the primary metric for evaluating reproductive performance, and pregnancy hard count or pregnancy inventory should be reserved for forecasting calving patterns.

3. **How efficiently are eligible cows becoming pregnant?**

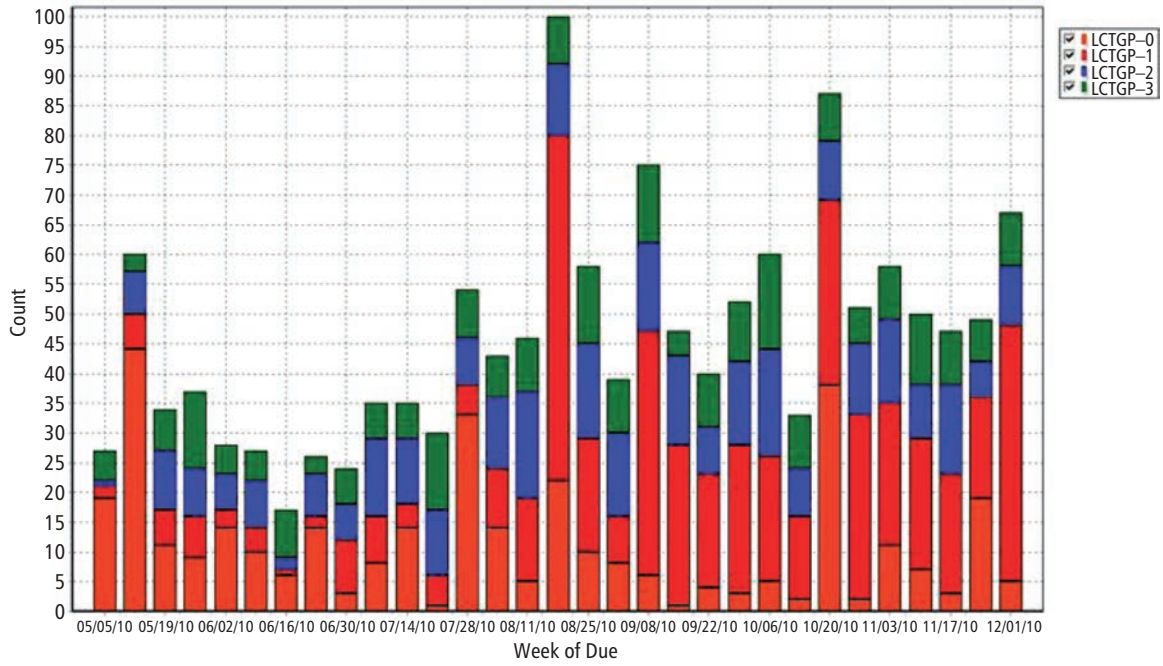

Figure 22.6. Pregnancy inventory graph for a herd milking 1600 cows, displayed by week of the year the cows are due to calve. The orange, red, blue, and green columns represent the number of heifers, first lactation cows, second lactation cows, and third and greater lactation cows, respectively, that are due to calve for each corresponding week indicated on the "*x*"-axis.

The single best metric for evaluating reproductive efficiency is PR, defined earlier in the chapter as the historical rate at which eligible cows became pregnant (number pregnant/number of eligible cow cycles). To be considered as eligible or at risk for PR, a cow must be past the voluntary waiting period (VWP), not already pregnant at the start of the 21-day period of interest, must have a known outcome at the end of the period under consideration, and must be present and eligible for pregnancy for at least half of the 21-day period. A "do-not-breed" (DNB) is a code that is assigned to cows that are destined to be culled. These cows are considered no longer eligible for breeding or pregnancy and are removed from the *future* reproductive statistics. Historical data involving DNB cows remain in the calculations. In most herds, 1%–3% of cows are coded as DNB. In DairyComp 305, the standard VWP is 50 days in milk for cows and 365 days of age for heifers. Historically, these points in time have been very popular and successful starting point for breeding programs. In well-managed farms, most cows should be cycling during the 50–70 days in milk window and most heifers should be of adequate size and cycling by 12 months of age. Without indicating a specific VWP, PR within DairyComp305 rate will be calculated using the default of 50 days in milk for cows and 365 days for heifers.

a. **What is the herd's annual PR and has it changed recently?**

When the 21-day PR report is run, the VWP by default is 50 days in milk and the time span is the most recent year. Within this single report (see Table 22.4), the insemination risk and the PR can be examined by 21-day calendar period, as well as the average insemination risk and PR for the entire time period under consideration. In Table 22.4, the average PR for the entire period under evaluation is 21% and the average insemination risk is 61%. However, performance appears to be declining, especially in the most recent time periods. In comparing the June and July time periods from 2008 with the most recent time periods, it is apparent that PR has declined from the range of 17% to 20% down to 10% to 17%. At the same time, insemination risk has declined as well. An examination of this report, created on September 22, 2009 suggests that insemination risk is much higher in the current 21-day cycle. However, the current cycle excludes cows that have been inseminated in the previous 21-day cycle and have not yet been determined to be nonpregnant or observed in estrus. As this population moves through time and more nonpregnant cows are identified, the true eligible population will increase in size while the number of animals that received

Table 22.4. A 21-day PR report for a dairy herd using an estrus detection-based AI program and no bull breeding

Date	Br Elig	Bred	Pct	Pg Elig	Preg	Pct
6/17/2008	401	240	60	390	74	19
7/8/2008	419	258	62	413	82	20
7/29/2008	467	294	63	460	79	17
8/19/2008	520	334	64	518	102	20
9/9/2008	574	382	67	564	118	21
9/30/2008	585	399	68	572	131	23
10/21/2008	544	348	64	535	117	22
11/11/2008	560	331	59	549	117	21
12/2/2008	550	333	61	533	120	23
12/23/2008	597	358	60	588	132	22
1/13/2009	610	374	61	599	146	24
2/3/2009	588	393	67	580	157	27
2/24/2009	538	338	63	525	139	26
3/17/2009	528	320	61	518	122	24
4/7/2009	528	342	65	519	123	24
4/28/2009	515	304	59	502	103	21
5/19/2009	517	298	58	510	108	21
6/9/2009	504	259	51	500	87	17
6/30/2009	543	338	62	531	63	12
7/21/2009	616	278	45	608	61	10
8/11/2009	711	407	57	0	0	0
9/1/2009	497	388	78	0	0	0
Total	10704	6521	61	10514	2181	21

an insemination will not change. Thus, the insemination risk will decline as the group moves through the next cycle or two. In general, accounting for the expected decline for this group, an insemination risk in this most recent cycle of ≥85% is a good target. Similarly, the two most recent PR cycles (shown in gray) may also change as they move through time but in this case, the tendency is to see the numbers increase as pregnant cows are identified. In these two cycles, the number of cows considered as eligible for pregnancy will remain relatively stable but the number of pregnancies may increase, depending on the lag between insemination and pregnancy evaluations. The further back in time that PR performance is examined, the more likely it is that cows that have not yet been pregnancy checked are to be pregnant, based simply on the concept that nonpregnant cows will eventually be observed in estrus and reinseminated, thus removing them from the population at risk.

b. **Is there a difference by parity or season?**

Often, due to the effects of heat stress or other environmental challenges, herds may have dramatic swings in reproductive performance across the year. Figure 22.7 represents a PR report across a 2.5-year time period and shows the variation across time in PR and insemination risk. Notice the pronounced drops in performance during the summer months of July and August. The black bars represent 95% CIs for PR for each 21-day period. Often, there are differences between parities as well. Usually, first lactation animals have a higher PR than second lactation cows, and both first and second lactation animals usually have higher PRs than cows in their third lactation or greater. If this pattern is not observed, questions should be posed about how heifers are being grown, if cyclicity issues exist, if calving problems are present, and so on. Another factor that can negatively impact young cow reproductive performance includes stocking density problems since younger cows tend to be smaller and more subordinate as compared to the older and often larger, mature cows.

c. **Is the herd using AI only, natural service sires only, or a combination?**

Within DairyComp305, the default 21-day PR is for AI only. In herds that utilize bulls, either in a cleanup role following AI or as the sole means of producing pregnancies on-farm, the mathematical approach for calculating PR is exactly the same, but the specific reports differ slightly. When bull breeding information is evaluated, actual inseminations are very rarely recorded and thus, the apparent insemination risk is usually of no value and should be ignored. Comparison of AI versus bull breeding efficiency using PR reports is problematic in distinguishing all but the largest of differences since the populations at risk in each scenario can be quite different. For example, in herds that rely on bulls primarily as a "cleanup" option for reproductive management, the bulls often gain exposure to cows only after unsuccessful attempts at AI. In addition, cows that are known to have reproductive problems are often moved directly into a bull pen without spending any time in the AI group.

4. **Are pregnant cows remaining pregnant?**

Pregnancy wastage or loss is common in dairy herds and the apparent or perceived level of loss varies depending on the time since insemination that pregnancy determination is performed and on each herd's baseline abortion risk. In general, the largest

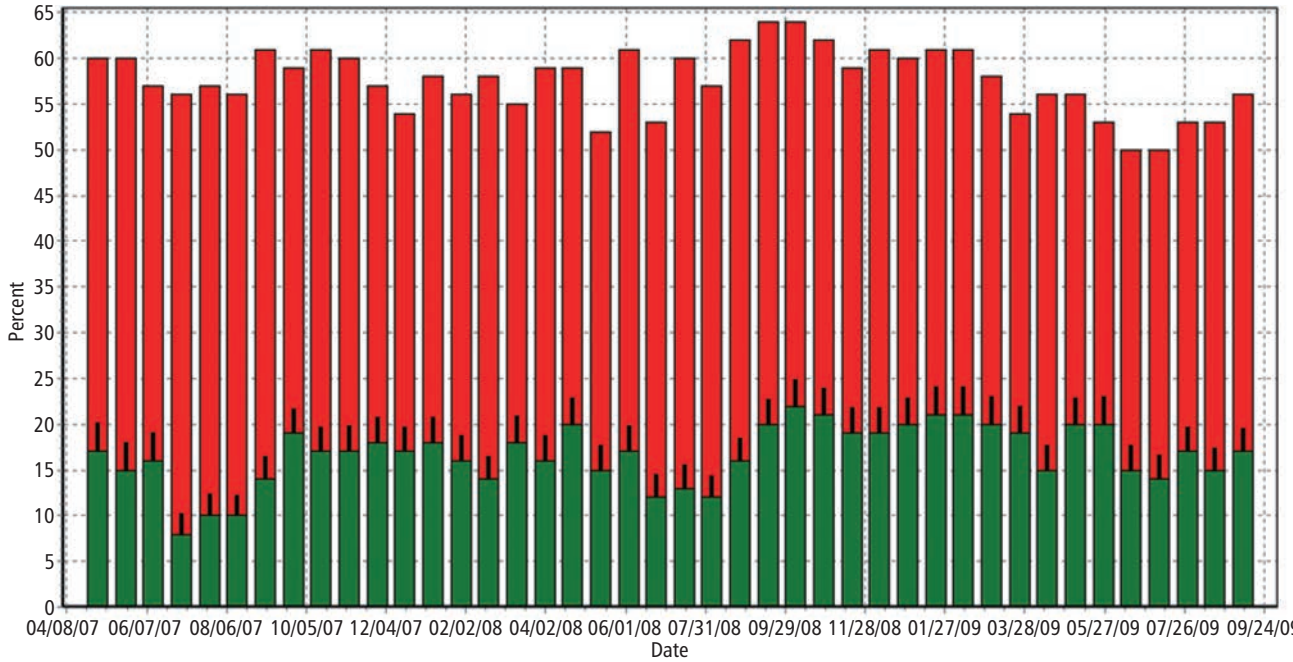

Figure 22.7. A 21-day PR report across a 2.5-year time period showing the variation across time in PR and insemination risk. Notice the pronounced declines in performance during the summer months (July and August). The black bars represent 95% confidence intervals for PR for each 21-day period.

degree of pregnancy loss occurs prior to day 17 postbreeding. These losses are termed early embryonic loss. Until there is a reliable test to diagnose pregnancy prior to day 17, these manifest themselves as an apparent reduction in conception risk. Losses occurring from approximately day 17 through day 42 are termed late embryonic loss and lead to a prolonged interestrus interval due to survival past the point of normal luteolysis in nonpregnant cows. Pregnancy losses occurring after day 42 of gestation are formally termed as abortions. However, most people define abortion as a breeding that was diagnosed pregnant that was later diagnosed open—that is, they almost never identify the exact date the cow aborted.

Depending upon when pregnancy diagnosis is performed, pregnancy losses may be interpreted as a depressed conception risk, as embryonic loss, or as abortions. In herds that perform a pregnancy evaluation at day 28, the apparent conception risk will appear 10%–20% higher than an identical herd that waits until day 40 to determine pregnancy status. Similarly, the apparent level of embryonic loss (often mistakenly called abortions) will be 10%–20% higher in the ultrasound herd simply as a result of earlier evaluations and not due to any damage caused by the earlier evaluation (Vasconcelos, 1997; Santos et al., 2004). Assuming that pregnancy determination is performed at approximately 40 days postinsemination, and allowing for a typical gestational abortion risk of 12% and an additional loss of 2% of pregnancies due to culling for other issues, a herd must produce about 7.6% new pregnancies per month in the lactating herd or about 5.3% new pregnancies per 21-day period to maintain a stable herd size with consistent calvings throughout the year. In heifers, the risk of abortion loss or culling is less, but to account for these losses, the monthly target for new pregnancies should be about 3.4% new pregnancies per month from heifers or about 2.4% per 21-day period.

5. **What are the voluntary waiting period and the pattern for days to first service?**

Cows do not return to normal cyclicity all at once following calving, nor do they all complete uterine involution at the same speed. In addition, there are different philosophical approaches toward breeding cows for the first time. As a result, cows may experience significant variation in days to first service. Also, herd managers may state that they have a certain VWP, but their breeding records reflect something entirely different. When examining the pattern of days to first service and estimating the true VWP, it is customary to allow 3%–5% early inseminations prior to establishing the herd's true VWP in practice. These early inseminations are considered outliers and do not usually reflect the owner's stated intentions for

breeding management. For example, look at the information presented in Table 22.5 and Figure 22.8. These data were taken from the DairyComp305 records of a large dairy herd that utilizes a combination of estrus detection and timed AI for first service. The "true" VWP is estimated to be approximately 53 days in milk as 3.6% of all first inseminations have occurred by this time. Inseminations prior to this period of time reflect more individualistic behavior (early cycling cows displaying estrus that were inseminated by technicians earlier than normal for the herd). This point is reflected in Figure 22.8 by the solid horizontal line.

Table 22.5. First insemination information stratified by days in milk for a large dairy herd

Range (DIM)	# of First inseminations within the range	Total first inseminations	Cumulative percent first inseminated
1–50	26	1847	1.4%
51	18		2.4%
52	23		3.6%
53	60		6.9%

a. **Given a certain voluntary waiting period, how efficiently are eligible cows becoming pregnant?**

Once the VWP is established, the efficiency with which cows are first inseminated can be evaluated using specific goals depending on the management approach taken. For example, in a herd with perfect estrus detection efficiency, the average interval to first service should theoretically be = VWP + 11 days; that is, all cows should be inseminated within the first 21-day cycle (note: this assumes that all cows experience a standing estrus every 21 days and that all cows are cycling). However, it should be apparent that this goal is unrealistic. A more reasonable goal (assuming 70% insemination risk and 21-day cycles) would be to have 90% of all first inseminations occurring within the first 45 days of the VWP. If a total timed AI approach is taken for first service, a reasonable goal would be to have 90%–95% of all cows inseminated within 7 days of the VWP if the program is performed weekly or within 14 days of the VWP if the program is performed using 2-week calving cohorts. If a hybrid program consisting of estrus detection followed by a timed AI is utilized and weekly calving cohorts, a reasonable goal is to have 90%–95% inseminated within 30 days of the VWP. Using the herd's actual VWP to calculate PR is a reasonable tool to

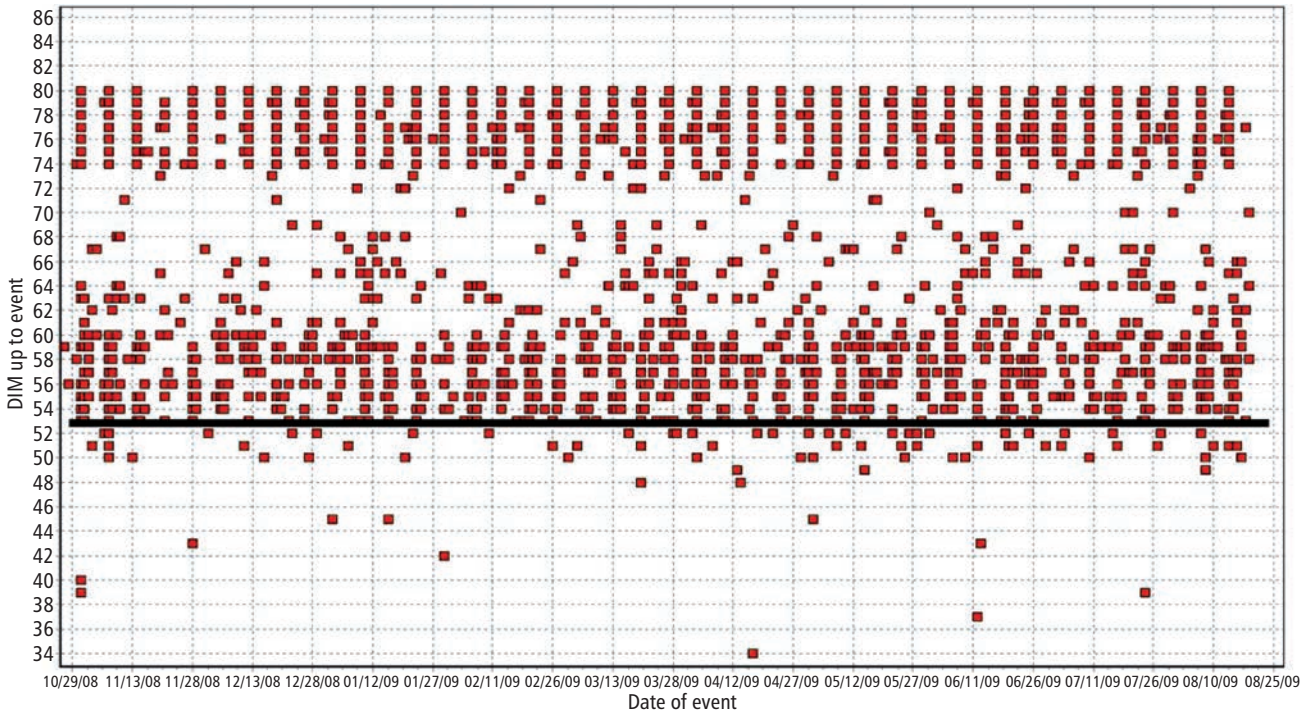

Figure 22.8. Scatter plot of days to first insemination (*y*-axis) by event date (*x*-axis) for a large dairy herd that utilizes a combination of estrus detection and timed AI for first service.

Table 22.6. Bredsum report from DairyComp305 for large Holstein dairy taken from on-farm records on 8/20/09

A	B	C	D	E	F	G	H
Date	Br Elig	Bred	Pct	Pg Elig	Preg	Pct	Aborts
8/7/2008	739	496	67	712	140	20	19
8/28/2008	818	563	69	792	167	21	20
9/18/2008	792	525	66	774	139	18	16
10/9/2008	814	543	67	785	177	23	19
10/30/2008	808	533	66	784	170	22	23
11/20/2008	763	481	63	737	159	22	24
12/11/2008	737	506	69	728	189	26	22
1/1/2009	731	458	63	719	194	27	18
1/22/2009	687	454	66	667	165	25	22
2/12/2009	674	461	68	660	153	23	19
3/5/2009	690	459	67	678	186	27	14
3/26/2009	637	464	73	622	172	28	11
4/16/2009	625	419	67	614	155	25	9
5/7/2009	659	436	66	644	139	22	5
5/28/2009	721	464	64	706	150	21	3
6/18/2009	736	491	67	725	137	19	1
7/9/2009	758	493	65	0	0	0	0
7/30/2009	625	528	84	0	0	0	0
Total	11631	7753	67	11347	2592	23	245

evaluate how well the herd is performing, given the design of the program, but caution is warranted for this approach. Some herds have been advised to delay the first breeding until later in lactation. However, the longer a herd waits to start breeding, the higher the performance has to be in each cycle in order to "catch up" to a more customary 50 or 60-day VWP. Merely changing the VWP to make the new PR look better (as analyzed from the new VWP) is doing a disservice to the herd's overall reproductive efficiency if cows run out of time and incur longer days open. If a herd elects to use a later VWP, performance should still be evaluated relative to the customary 50- or 60-day VWP to account for this "lost opportunity" time at risk for breeding.

b. **Are there any issues with insemination risk? Is insemination risk sufficiently high and consistent to generate an adequate PR?**

The evaluation of insemination risk can be approached in one of two ways: (1) by 21-day calendar date or (2) by cycle number following the VWP (first 21-day cycle, second cycle, etc.). When investigating current reproductive performance or looking for evidence of recent changes, the only legitimate approach is to look at insemination risk by calendar date, as shown in PR report illustrated by Table 22.6. The insemination information is shown in columns B, C, and D. Column B displays how many cows were eligible for insemination during each 21-day period; column C displays how many cows were actually bred during that same period; and column D displays the calculated insemination risk, first by 21-day period, and then at the bottom, it shows the average for the past year, not including the two most recent cycles. The two most recent cycles, dated July 9 to July 29, 2009, and July 30, 2009, to the current date of the report (August 20, 2009), represent preliminary information, especially the most recent one. In the current cycle, it shows that 625 cows are eligible for insemination and 529 cows have been bred, resulting in an insemination risk of 84%, which is well above the year's average of 67%. However, the population at risk is incomplete since it excludes nonpregnant cows that have been inseminated, but not yet evaluated for pregnancy and missed on the 21-day return to estrus.

As this population of animals moves through the system, further information regarding the true nonpregnancy status will be discovered, and these cows will be added back to the eligible population, thus lowering the true insemination risk. In AI herds that are not relying solely on timed AI, an achievable goal for insemination risk for each of the "normal" cycles and for the average is about 65%–68%. When Holstein herds reach 70% or more by estrus detection only, the accuracy of estrus detection is often challenged. However, in examining the most current cycle, because it is biased upward due to incomplete information of the true nonpregnant population, an achievable goal for this single cycle is 85%–90%. In total timed AI herds that do little to no estrus detection, insemination risk may approach 100% for individual cycles, but usually only every other cycle since only known nonpregnant cows can be inseminated using a timed AI protocol. As a consequence, average insemination risk across multiple cycles for this type of herd management usually runs in the upper 50s to about 60%, once the "off" cycles are included in the calculation as well.

The approach of evaluating insemination risk by 21-day calendar date has the distinct advantage of more quickly reflecting change in the system than option two, the evaluation by cycle number following the VWP. In the latter option, which should never be used for monitoring trends in performance, recent change (positive or negative) is dampened by the momentum of many additional cows across time, dramatically diminishing the ability to detect change. However, evaluation by cycle number can reveal information about historical management approaches to breeding. For example, with heavy use of timed AI, the first breeding cycle should reflect 95% or higher insemination risk, but much lower numbers in the second cycle. The third cycle should reflect a high insemination risk, but slightly lower than the first. As time moves on, the alternating high–low figures for insemination risk become muted as breeding intervals begin to overlap since most resynchronization schemes are not set up on exactly 42-day reinsemination patterns.

c. **How efficiently are cows being reinseminated if not pregnant?**

One of the keys to achieving high reproductive performance is to promptly and accurately reinseminate nonpregnant cows. Rebreeding cows can be done through the use of estrus detection, by using timed AI or by using natural service sires. If timed AI is used, the interval between insemination and the subsequent insemination will be influenced by the frequency of herd visits, how early cows are checked following insemination, the type of resynchronization being used, and the compliance to the program (i.e., what percent of the cows actually receive the injections and semen). In estrus detection-based breeding programs, breeding intervals are largely the result of estrus detection efficiency and accuracy, but may also be affected by late embryonic death risk.

Heat interval analysis reports are common in dairy management software programs, but their use should be discouraged. Heat interval analysis historically was used as an aid in investigating reproductive issues within estrus detection-based breeding programs. Within this specific context, interval analysis had limited utility. Typically, the intervals evaluated covered a large period of time (momentum issue) and use of this approach rarely helped detect or answer important breeding questions due to the variety of factors that can impact each interval. Table 22.7 shows reasonable expectations by time range along with a few of the potential key drivers for each interval. With the advent of estrus synchronization and ovulation synchronization programs, interpretation and use of heat interval analysis is usually of little value. In herds that rely heavily on timed AI, the vast majority of intervals should be in the 36- to 48-day range, depending on the frequency of herd visits and reenrolment of cows. In herds that incorporate estrus detection but still use some form of timed AI, the distribution across intervals will change depending on the program utilized, the strategy for resynchronization, and the estrus detection efficiency. For example, in herds that utilize Double Ovsynch (Souza et al., 2008) for total timed AI for first service, there is typically a reduction in the proportion of cows in the first two intervals (1–3 days and 4–17 days) as a consequence of putting cows through a setup Ovsynch protocol prior to enrolling them into the breeding Ovsynch in which they actually receive semen. Anestrus anovulatory cows that go through a single Ovsynch (alone or following presynchronization with prostaglandin products) but fail to become pregnant often display estrus 8–12 days following the Ovsynch insemination due to the stimulatory effects of the gonadotropin-releasing hormone (GnRH) injections on follicular turnover. However, in the case of Double Ovsynch, as a result of going through the first Ovsynch as a setup and then going through

Table 22.7. Heat intervals, goals, and interpretation guidelines

Heat interval	Goal with estrus detection	Comments/interpretation
1–3 days	<5%	Usually represents estrus detection accuracy issues; it may increase with aggressive breeders that breed on first signs of estrus or that like to rebreed questionable heats
4–17 days	<10%	Often represents estrus detection accuracy issues; in herds that utilize timed AI and estrus detection, often see a spike in percent of second services that fall in this category due to anestrous, anovulatory cows completing an Ovsynch program for first service that then initiate cyclicity and show an estrus 8–12 days later.
18–24 days	>40%	Normal, expected interestrous interval. The ratio of 18–24 to 36–48 intervals should be about 3.5:1 in herds utilizing estrus detection-based breeding programs.
25–35 days	<15%	Class interval that is associated with late embryonic death. May also result from inaccurate estrus detection for previous service followed by a missed normal estrus.
36–48 days	<15%	Normal expected intervals for cows that cycle normally but were missed at the previous estrus. Also possible with late embryonic death.
Over 48 days	<10%	A variety of issues is possible including poor estrus detection, resumption of anestrus anovulatory condition, late embryonic death, or early abortion.

the regular breeding Ovsynch, most anestrus anovulatory cows receive sufficient stimulation from the GnRH injections and the resulting progesterone priming that few cows display the very short return to estrus. The use of any estrus or ovulation synchronization program also changes the apparent intervals between heats. If a GnRH injection is given during proestrus, cows should respond by ovulating to the induced luteinizing hormone (LH) surge but often will fail to display signs of estrus. In addition, resynchronization by using Ovsynch for nonpregnant cows in effect creates a limit to how far cows may go past the previous breeding without being reinseminated again, assuming that pregnancy evaluations are done promptly and consistently, and good protocol compliance is maintained.

In the quest to improve reproductive performance in herds using AI, the intensity and accuracy of estrus detection, the frequency of pregnancy evaluations, the stage of gestation for the pregnancy exams, the type of timed AI program for first service, and resynchronization as well as the compliance to the program(s) used are all very important elements that impact the overall insemination risk. Instead of simply evaluating heat intervals, a better approach would be to measure the risk (and rate) of becoming pregnant following an "*open*" diagnosis. For example, consider a herd (herd "H") that relies completely on estrus detection and AI for reproductive management. If the average insemination risk for this herd is 50%, which is typical for many herds in North America, without the use of any estrus or ovulation synchronization, the average interval to rebreeding will be approximately 31 days. Compare these results with herd "S," a herd that utilizes estrus detection with the same efficiency as herd "H," but also utilizes timed AI, performs pregnancy exams on a weekly basis at 35 to 41 days since last insemination, and gives a GnRH injection the week prior to the scheduled pregnancy examination. The average days to the next service for herd "S" is approximately 24 and reflects a savings of 7 days of lost opportunity as compared to herd "H." If the comparison is made starting from the diagnosis of "open," the differences are even larger. Dairies that resynchronize cows with a GnRH injection the week prior to pregnancy exam can get almost all of their open cows reinseminated within 3 days. Of course, the goal is pregnancy and not merely insemination, but cows must be first be inseminated in order to become pregnant.

d. **Are there any issues with conception risk?**

Conception risk has historically been a very key measurement when evaluating reproductive efficiency in dairy herds. While PR has surpassed CR as a primary metric, CR is a key influencer of PR

and must also be evaluated. However, investigating CR problems is difficult because it can be affected by a wide variety of problems and, since it is a binomial outcome, a significant number of inseminations are necessary in order to develop any real confidence about the results. In general, the evaluation starts by examining the overall CR for the herd, followed by stratification by service number. Typical whole herd CR in North American dairy herds usually range from 30% to 35%. If cows are serviced via estrus detection only, first service CR may be several points higher than subsequent services. In general, CR for services 1 through 5 are usually very similar with a slight decrease after fifth service, if sufficient numbers of services are available for adequate evaluation. In all but the very largest herds, there often are not enough inseminations in each of the later service numbers to comprise a robust sample for comparison.

Other questions that might be asked in the investigation of CR issues are included below:

i. Is first service conception risk acceptable?
ii. Does conception risk change appreciably across time?
iii. Are there any problems by parity?
iv. Are there any problems by breeding code or method?
v. Is there a seasonal or calendar effect on conception risk?
vi. Are there any technician issues affecting conception risk?

As important as it is to evaluate technician performance, this is very difficult. First, there can be substantial confounding. Perhaps due to scheduling, one technician breeds more synchronized cows and another breeds more standing heats. Or one technician started breeding in the winter and the other has been breeding year-round. Even more suspect is trying to evaluate the performance of a new technician. Because failures (reinseminated cows) are known prior to successes, new technicians need to only be evaluated on breedings that have occurred at least 42 days earlier so there are known outcomes on all breedings.

e. **How timely are pregnancy evaluations performed?**

One of the keys to improving reproductive efficiency is to promptly identify nonpregnant cows and take an action that will improve the likelihood of them becoming pregnant in a timelier manner in the near future. Consequently, the timing and frequency of pregnancy evaluations should be examined to determine if opportunities exist for improvement. For the remainder of the discussion of this topic, days from insemination to pregnancy determination for cows that were identified as pregnant on that exam will serve as the focal point of the discussion. The actual number of days from insemination to pregnancy determination is not nearly as important as how efficiently the nonpregnant cows are identified and reinseminated. However, the days to pregnancy determination for pregnant cows is a good proxy for evaluating management approaches and effectiveness and is not confounded by estrus detection, as is time to reinsemination of nonpregnant cows.

Figure 22.9 shows a frequency histogram of the days from insemination to pregnancy diagnosis for cows diagnosed pregnant. This herd utilizes a mixture of timed AI and estrus detection-based breeding with use of natural service. The red columns represent the days since breeding for the first pregnancy evaluation and the blue columns show the days since breeding for the verify check (or second pregnancy evaluation). Finally, the green bars represent the days since breeding for confirmation of pregnancy prior to moving cows from the lactating to dry cow group. The goal of this herd is to perform the first pregnancy evaluation starting at 35 days since the last insemination. Since this herd performs weekly checks, most cows should be checked for the first time between 35 and 41 days since the previous breeding. In this case, 94% of cows were checked during this window of time. Most of the remaining cows were recorded as pregnant during the subsequent week. These cows were likely classified as "rechecks" due to some questionable finding by the herd veterinarian or were simply missed due to an identification error or due to cows being in the wrong pen. As a consequence of the early start with pregnancy determination, heavy reliance on timed AI, and very good compliance within the system, the average days to pregnancy determination is 40 days. Note: In herds that do not use timed AI, perform few rechecks, and have excellent compliance with the presentation of cows for pregnancy determination, the average days from insemination to pregnancy diagnosis should be closer to the median of the interval, or in this case, approximately 38 days.

In the herd shown in Figure 22.9, the "verify exam" to determine who has maintained and who has lost their pregnancy starts at 70 days post-AI and 90% of cows were examined between 70 and 76 days. This second pregnancy evaluation is highly recommended in herds that perform

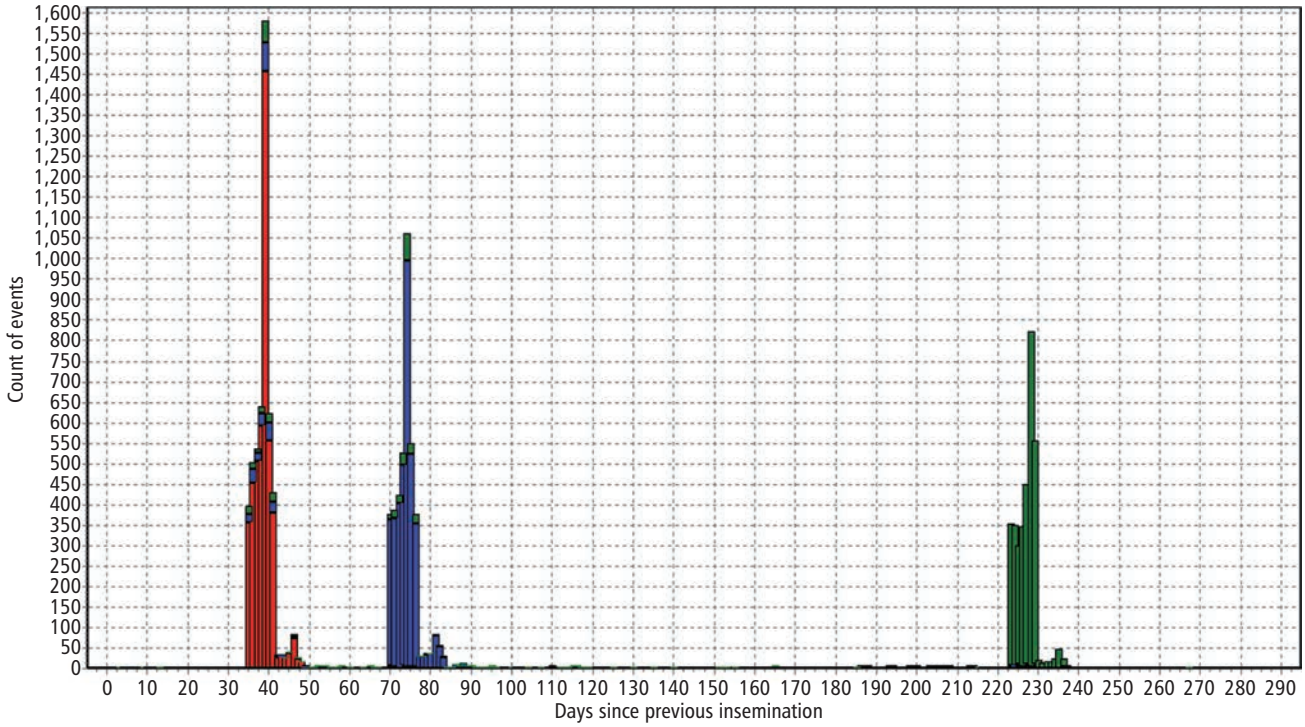

Figure 22.9. A graph of days since the last insemination at the time of pregnancy diagnosis for cows checked pregnant in a herd using a mixture of timed AI and estrus detection and no natural service. The red grouping is the first pregnancy evaluations, the blue is the second pregnancy evaluation and the green represents the confirmation of pregnancy just prior to drying cows. The *x*-axis represents days since the last insemination and the *y*-axis is a count of events (cows).

early pregnancy diagnosis (35 to 45 days post-AI) and will help identify open cows that aborted much earlier than if the herd simply relied on estrus detection alone. The final pregnancy evaluation is performed just prior to moving cows from the lactating pens and placing them in the dry pens. This exam is to identify cows that may have aborted and to avoid drying and treating cows that are actually open. In this herd's case, the plan is to confirm all cows between 223 to 229 days since breeding and 94% of cows are checked during this time period. The herd illustrated in Figure 22.9 is doing an excellent job within the context of their stated pregnancy evaluation plan.

In contrast, consider the herd shown in Figure 22.10. Once again, a frequency histogram of the days from insemination to pregnancy diagnosis for cows diagnosed pregnant is shown. This herd utilizes a mixture of AI based on estrus detection, natural service sires, and a small amount of timed AI. The red grouping is the first pregnancy evaluations, and the blue bars represent the second pregnancy evaluation. This herd begins their pregnancy evaluations at 41 days post-AI and performs these checks every 2 weeks. As a consequence, the expected range for first pregnancy determination ranges from 41 to 54 days. However, only 79% of the cows are evaluated within this range, and the average days to pregnancy determination is 54. (Note: Cows that became pregnant due to bull exposure were removed from this calculation. The number of days postinsemination in bull-bred herds is a function of frequency of evaluation and technical skill of the veterinarian.) Due to poor compliance, many cows were missed and were not evaluated until much later in gestation. If this is occurring in pregnant cows, it is also occurring in nonpregnant cows and is contributing to delayed intervals to reinsemination.

In the herd pictured in Figure 22.10, only two pregnancy examinations are scheduled. This practice is common in herds that perform the initial evaluation later in gestation and the value of a second exam to identify cows that have lost the pregnancy is reduced due to the delayed time to first examination. The second examination in this herd takes place between 165 and 225 days of gestation. In herds that utilize natural service sires, a common practice is to move pregnant cows into the natural service pens. Cows in these pens may be subjected to exams every 1.5 to 2 months, thus

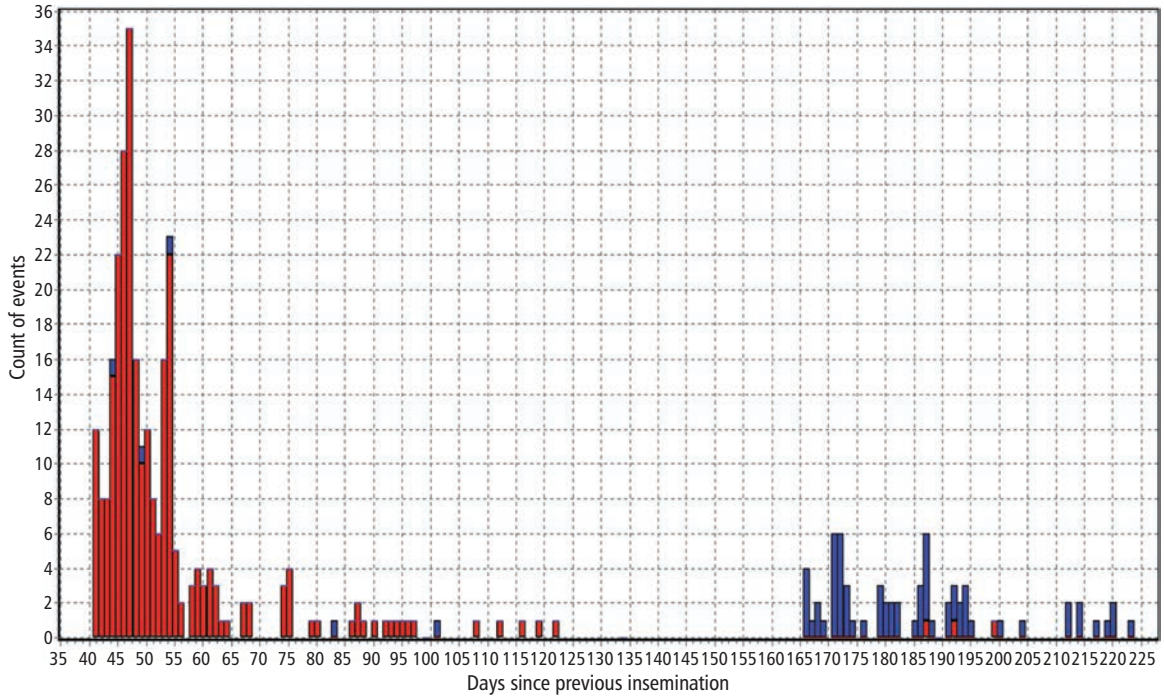

Figure 22.10. A graph of days since the last insemination at the time of pregnancy diagnosis for cows checked pregnant in a herd using AI based on estrus detection, natural service sires, and a small amount of timed AI. The red grouping is the first pregnancy evaluations and the blue represents is the second pregnancy evaluation. The *x*-axis represents days since the last insemination and the *y*-axis is a count of events (cows).

increasing the variation in time at the second examination.

Finally, in Figure 22.11, a graph of days since the last insemination at the time of pregnancy diagnosis for cows checked pregnant in a herd with a heavy reliance on timed AI and no natural service is shown. This herd utilizes ultrasound to evaluate the pregnancy status of cows at 31 to 37 days, but since there is a heavy reliance on timed AI, most of the cows are being evaluated at 32 days post-AI. One problem with utilizing ultrasound for pregnancy evaluation at 28–34 days is that a substantial proportion of cows (often ranges from 8% to 15%) is likely to experience pregnancy wastage by approximately 42 days. If no additional evaluation is performed until the verify exam at approximately 70 days, there is a substantial lost opportunity for reinsemination of the cows experiencing pregnancy loss. Therefore, a common recommendation for herds that perform pregnancy evaluations prior to 35 days is to do an early verify exam, typically 14 days after the initial exam, in order to identify cows that have experienced late embryonic or early fetal loss. In herds using ultrasound for early diagnosis, a potentially better approach would be to identify the nonpregnant cows at the first examination (an "open cow check" instead of the traditional "preg check") and not to record the cows found pregnant until the second examination 2 weeks later. This approach would reduce the artificially high abortion risk that is commonly found in ultrasound herds and still allow action to be taken on the nonpregnant cows. Since this herd is checking and rechecking early, the typical verify exam is slightly later (76–82 days), and the final confirmation prior to movement into the dry pen is performed at 211–217 days post-AI. The additional exam that is performed 2 weeks after the initial evaluation is one of the necessary but often undisclosed costs associated with using ultrasound for earlier pregnancy evaluation.

f. **If natural service sires are used for reproductive management, the options for record analysis are much more limited, but there are still a few important questions that should be asked:**
   i. **What is the pattern for movement of cows into bull pens?**

      In many herds that utilize both AI and natural service sires, nonpregnant cows are often moved to bull pens too quickly, that is, managers quit trying AI too quickly and move them to the bulls believing that the likelihood of becoming pregnant will be greater in the natural service pens. However, in a study using

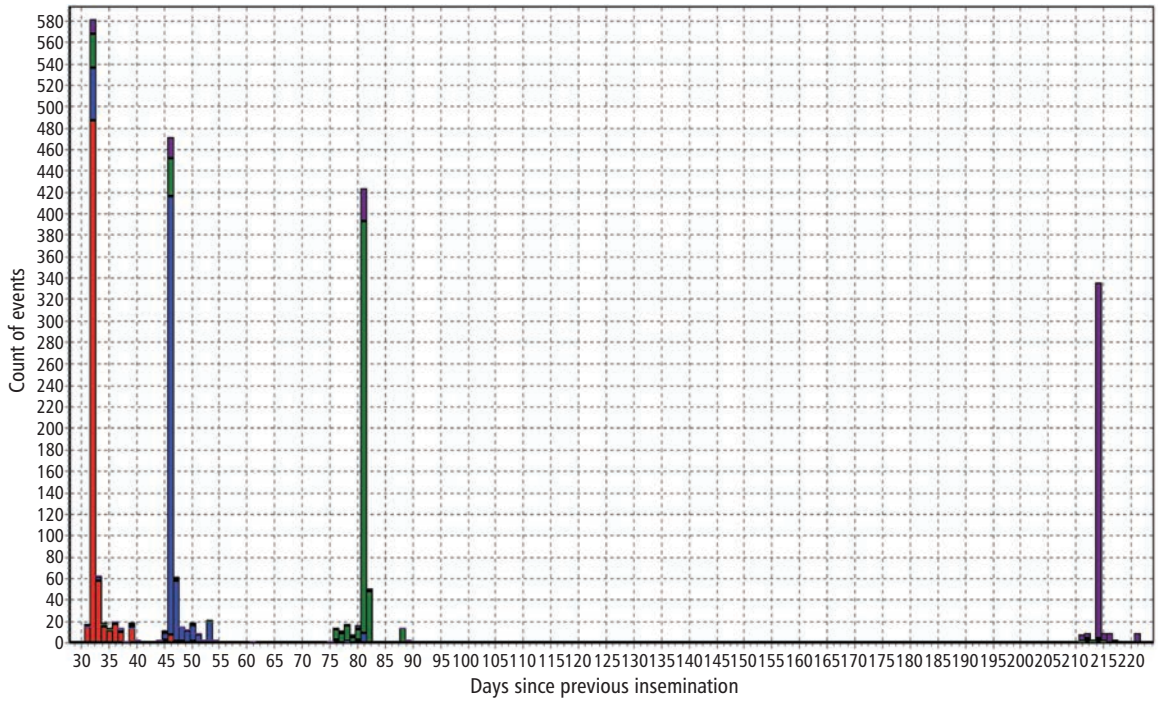

Figure 22.11. A graph of days since the last insemination at the time of pregnancy diagnosis for cows checked pregnant in a herd with a heavy reliance on timed AI and no natural service. The red grouping is the first pregnancy evaluations (performed with ultrasound), the blue is the second pregnancy evaluation, the green represents the third pregnancy evaluation and the purple corresponds to the confirmation of pregnancy just prior to drying cows. The *x*-axis represents days since the last insemination and the *y*-axis is a count of events (cows).

data from 10 large California dairy herds that utilized a combination of AI and natural service, the conclusion reached was that cows were more likely to get pregnant if they remained in the AI pens (Overton & Sischo, 2005).

ii. **How efficiently are cows becoming pregnant when moved with the bulls?**

The reproductive efficiency of natural service breeding can be evaluated by using PR as long as the appropriate coding or recording is maintained and pregnancy evaluation results are promptly performed and entered into the record system. Although the PR reports will typically show an insemination risk along with the PR, the insemination risk is underestimating the true insemination risk since herds do not commonly record insemination attempts by the bulls.

g. **Is there a problem with pregnancy wastage?**

Pregnancy wastage has been mentioned several times already, but a few more comments are warranted. First, the classic "abortion rate" is nearly impossible to accurately calculate since most herds do not know exactly when a cow experiences a loss of pregnancy. Instead, what is known is when the cows were determined to no longer be pregnant. Based on this information and the condition of the uterus at the time of the examination, an estimate is made of when the true abortion occurred. However, depending upon the frequency of evaluations and the level of daily observations, this estimate can be dramatically different from reality. Without accurate dates of occurrence, a true abortion rate cannot be established.

Second, if a calculation of abortion risk is made, the numerator and denominator need to be clearly defined. The correct approach would be to count the number of abortions that have occurred and divide this number by the number of pregnancies at risk of abortion (i.e., number of aborts/number of aborts + number still pregnant over some specified period of time). Between record systems, there is considerable confusion as to what constitutes an abortion, how many aborts have occurred, and how many pregnancies were truly at risk.

Third, to truly calculate an annual abortion risk (historical performance), the data range under consideration must go back in time starting about 20 months previously and the number of aborts that occurred from that point until about 8 months ago determined. (Note: The reason for using this

specific 12-month time period is that it represents the most recent year of data that is available for evaluation of cows that have had a full gestation at risk.) Using the same time range, one should count the number of pregnancies at risk. This approach, though epidemiologically sound, is very historical in nature (too much lag) and does not reflect the current level of performance.

Perhaps, the best way to monitor pregnancy loss in a timely and efficient manner is to perform a quick tally for specific time points after each herd visit. For example, if pregnancy evaluations are performed weekly, a quick time-specific abortion risk can be calculated by dividing the number of nonpregnant cows identified on the verify exam at 70–76 days by the sum of the nonpregnant cows and the pregnant cows identified on this same exam. For example, 2 cows previously identified between 35 and 41 days post-AI as pregnant were identified at the verify exam (70–76 days) as not pregnant and 47 cows were found pregnant within the same initial and verify exams. In addition, there was another cow that was in the same contemporary group (previously identified as pregnant 35 days ago) that was found to be in estrus and reinseminated last week. The estimated abortion risk is $(2 + 1)/(47 + 2 + 1) = 6\%$. In most dairies that follow this type of pregnancy evaluation schedule, 5% to 7% of cows are found to have aborted by the first verify exam. A similar approach can be taken with the late pregnancy confirmation exam, but a similar or lower abortion risk is expected despite the longer gestational time at risk.

6. **What are the opportunities available to improve performance?**

   Reviewing records should help determine if there are opportunities to improve insemination risk, conception risk, increase the frequency of pregnancy evaluation, and so on. However, there are also other opportunities that should be considered:

   a. **Are there cows that need to be inseminated?**

      Are there cows that are past the typical first service breeding window that have not been identified as reproductive culls and are currently still in the AI pens that have not yet been inseminated? If so, these animals need to be identified and a plan implemented to get these cows inseminated.

   b. **Are there cows that need to be evaluated for pregnancy?**

      Are there cows that are past the typical window for pregnancy evaluation that have not been examined? In other words, if the first pregnancy evaluation is performed at 35–41 days, are there cows that are 42 days or more since the last insemination that have not yet been checked?

Transition Cow Performance Monitoring

In order to obtain and maintain high reproductive efficiency and high milk production, herds must do an excellent job of transitioning cows from the dry period into lactation. The transition period, typically classified as the last 3 weeks of gestation through the first 3 weeks of lactation, is a critical time in cows' lactations with long lasting carryover effects that extend far beyond a high risk of early lactation culling. There is a well-documented depression in the immune function during this 6-week period. Dry matter intake (DMI) may drop by 30% or more and the presence of various environmental, social, or feed-related stressors may further compound the compromised DMI and immunity. Early lactation milk production, risk for contracting infectious diseases and receiving antibiotic treatment, complications of metabolic issues such as hypocalcemia and ketosis, return to positive energy balance, and reproductive efficiency are all related to the success of the transition period.

Veterinarians, nutritionists, and other dairy consultants are often asked to investigate, correct, or otherwise deal with the resulting problems caused by transition failures. For example, herds that struggle with poor reproductive efficiency may implement massive changes in the breeding program including the firing of commercial or on-farm inseminators. Nutritionists may be called regarding poor fresh cow milk production or poor peak performance. Often, these production and reproduction problems are the result of mismanagement that occurred at least 3–6 weeks previously. Examples of management issues that may lead to production problems include overcrowded close-up dry and fresh cow pens, inadequate heat stress abatement, and rations that somehow were not delivered as per the nutritionist's recommendations or were sorted by the cows. Unfortunately, key herd advisors at times may resort to finger pointing and playing the "blame game." However, each member of the herd management team has specific roles. Complete buy-in and cooperation from all members of the management team, as well as a concerted management effort targeted at prevention of periparturient problems is necessary to ensure the financial success of all dairy enterprises.

Many issues may have an impact on transition cow health and performance. Records analyses is one important step in determining how well management is transitioning cows from nonlactating pregnant animals into

lactation but is no substitute for actually walking the herd, observing cows, and actively observing and investigating issues such as housing, cow comfort, nutrition, and general cow condition. In evaluating transition management and fresh cow health, the key is to once again ask appropriate questions and then find the data that answers the questions posed. A combination of onsite observations and records analyses can uncover many management problems. Key questions involving transition cow management include the following:

1. **What has been the pattern of calvings over time?**
   Are there large swings in the number of animals calving? These swings can result from the purchase of large groups of replacement animals, prolonged periods of reproductive problems, seasonal breeding challenges, and management decisions such as intentionally not breeding during certain months in order to avoid calving during periods of heat stress. Large swings in the number of animals calving can wreak havoc on even the best transition programs simply as a consequence of overcrowding the housing facilities or overwhelming management's ability to properly monitor and treat fresh cow problems. Other questions that should be asked include:
   a. What has been the pattern of twins, gender, and stillbirths across time?
   b. Are there differences by parity?
2. **What fresh cow disease issues are actually being recorded in a consistent manner?**
   Often, herds have the best intentions for recording fresh cow disease issues, but either fail to record them, fail to enter them into the record systems, or inconsistently record fresh cow events. Another issue that should be considered is the problem called detection bias. For example, if there are two different individuals evaluating fresh cows for ketosis, one of the workers may put a greater effort into detection and utilize urine dipsticks or some other test that is applied across all individuals in the fresh cow population while the other individual does not test until cows are showing clinical signs of disease. The apparent prevalence between these two individuals within the same herd can be dramatically different and as a consequence, diseases such as ketosis often should not be compared across herds due to the differences in detection or testing.
   a. **Do the patterns of fresh cow disease indicate any problem that needs further investigation?**
      One common problem that is observed when consulting on dairies is that an owner or manager may feel that the risk of some problem, such as metritis, is higher now than normal. The first question to ask is "are they simply referring to the crude number of cases being diagnosed or the true risk of disease across the population?" For example, a herd may be working through a larger than normal group of animals calving. As a consequence of nothing more than a larger population at risk, the number of individuals requiring treatment may be significantly larger than normal. However, it does not necessarily constitute a significant increase in the true risk of metritis in the population. In order to better gauge the magnitude of the problem, the risk for metritis should be calculated. For metritis, cows are considered at risk during the first 14 days in lactation. In order to calculate the metritis risk, the number of cows identified with metritis is divided by the number of animals considered at risk of developing metritis. For example, during the month of February, the dairy recorded 12 cases of metritis. Calculating the true population at risk can be a bit tricky. Cows that calved during the last 10 days or so of March that were not already recorded as having metritis in March would be considered at risk. Also, most cows that calved during April are at risk except for the ones that calved the last day or two of April (cows do not typically develop metritis on day 0 or 1 after calving). What about the cows that were present for 5 days and then were culled before they developed metritis? These cows did not experience the full time at risk. As already mentioned, determining the true population at risk can be difficult. One quick estimate that will approximate the true risk is to divide the number of new cases during the month by the number of animals that calved during that month. An assumption that is made in this approach is that the number of animals that calve month to month is relatively constant. While this is often not the case, for a crude estimation of risk on a dairy, this approach will usually be close enough to try and pick up changes across time. For problems such as retained placenta that are recorded within 24 h of calving, this approach is very accurate. For other issues, such as risk of displaced abomasum, which most commonly occurs during the first 30 days in lactation, there is a greater risk of introducing bias as a result of variable numbers of animals calving per month. Table 22.8 displays some of the more common postparturient issues affecting dairy herds, expected risks, cited ranges, and achievable goals for Holsteins (Curtis et al., 1983; Peeler et al., 1994; Kelton et al., 1998).

Table 22.8. Expected levels of common postparturient issues for Holstein herds, along with reasonable and achievable goals

Disorder	Mean (%)	Range (%)	Goal (%)
Milk fever	8	1–44	<5
Displaced abomasum	3.3	1–14	<3
Retained placenta	10	1–36	<8
Metritis	12.8	2–36	<10–15
Dystocia	13	2–36	<10
Stillbirth	6	1.4–11	<8

b. **Is there a difference in fresh cow disease risk by parity?**

Whenever a problem is suspected, parity-specific risk should be calculated if the herd size permits. Certain problems such as clinical hypocalcemia are related to parity, and the lactational distribution of the fresh cows must be considered before stating there is a problem or concluding that one does not exist.

3. **How is early lactation production across time? Does early lactation performance (first official test day milk, week-4 milk, or first projected 305me estimates) indicate any problems with individuals or specific groups?**

Performance of fresh cows is vitally important to the financial stability of a dairy, and it is critical to have good monitors that provide an indication of the success or failure of the transition program as rapidly as possible. Peak milk performance has historically been used to assess transition performance, but this metric has too much lag to serve as a tool for rapid assessment of the transition success or failure for groups of cows. Also, it is subject to bias in that it does not include the performance of cows culled prior to reaching peak milk.

To eliminate some of the problems affecting peak milk, there are other milk production metrics from the first test date that can be used to assess transition management and early lactation performance such as first test day milk production. However, there are some problems with this approach as well. When comparing first official test day milk production across individuals or across groups, a complicating factor is the impact of days-in-milk at first test date. For example, cows that have a first test at 10 days-in-milk are expected to produce less milk than cows that have a first test at 30 days-in-milk. The magnitude of the effect of days-in-milk on first test milk production estimates varies by herd; it depends on the peri-parturient nutritional management, periparturient disease risk, genetics, season, and parity. In general, first test milk may increase 0.25–1.5 lb (0.11–0.68 kg) or more from 5 to 40 days-in-milk for each additional day-in-milk at first test day. In large herds, to estimate how well a group of animals is performing, a restriction to a specific days-in-milk at first test can be made. For example, if the question was "how well are the first lactation animals that calved in June performing," the average first test day milk for first lactation animals that calved in June and had a days-in-milk at first test of 10–30 could be calculated. However, this approach can lead to a sample size that is too small to evaluate, and it excludes some individuals, thus, preventing the comparison of all individuals. In DC305, Dr. Eicker has developed an approach that estimates milk production as if the animal had actually tested on a specific week, such as week-4 milk. This approach may suffer a bit in accuracy at the individual cow level, but when applied to groups, appears fairly robust.

Most processing centers will offer predictions of the expected milk production over a standardized 305 lactation. This metric is called the projected 305 day mature equivalent milk production (p305me), and it adjusts for age of the cow and calving season to allow for the comparison of different parity groups at various stages of lactation. While not perfectly accurate in predicting the final completed 305-day production, it is a useful tool for early lactation performance in that it reduces the bias due to culled cow exclusions, allows for the comparison of different parities and different calving seasons, reduces the lag associated with peak milk, and removes the effect of day in milk on milk production.

a. **What percent of early lactation milk weights are below the targeted cut-points?**

A quick, crude approach to assess how well a group of animals has performed is to calculate the percent of animals that are less than 100 days-in-milk that are below some minimum cut-point of production. For example, with first lactation animals, the desired goal may be less than 10% of the cows producing less than 50 lb (22.6 kg)of milk at test date during the first 100 days. In mature cows, the goal would be to have less than 10% of cows producing less than 70 lb (31.7 kg) of milk at test date for animals in the first 100 days-in-milk. Rather than simply evaluating how well a herd has performed this month based on the percent of early lactation cows that are below 50 or 70 lb (22.6–31.7 kg), it may be more valuable to plot trends across time within the herd by parity group.

b. **Do the first test fat results suggest any problem?**

Using milk fat and protein results to assess health and performance is a controversial topic but one that has some merit if approached carefully. Early lactation animals are expected to lose 0.5–0.75 units of body condition score during the first 30–45 days in milk. Fat that is mobilized to support milk production is broken down into nonesterified fatty acids and can be utilized in a variety of ways: (1) it can be used by peripheral body tissues for energy, (2) it can go to the liver and be oxidized (completely or incompletely—resulting in ketone bodies) or be re-esterified into fat and stored in the liver, or (3) it can be taken up by the mammary gland, resulting in an increased level of fat in milk. The mammary gland is very efficient at removing these circulating fatty acids and placing them into milk, adding to the fat already present in milk that was synthesized within the mammary gland. In general, the higher the circulating level, the more that can be sequestered into milk. When evaluating milk fat percentage, various cut-points for milk fat percentage and for days in milk are used, but a common approach is to examine the percent of cows that are between 10 and 40 days-in-milk that have a butterfat percentage greater than 5.0 (Holsteins). In general, this level should be less than 10%. It must be remembered, however, that this screening approach is a herd-level tool and is less accurate at the individual cow level. If greater than 10% of the Holsteins that are between 10 and 40 days-in-milk have a butterfat level greater than 5%, further investigation should be performed to determine if conditions are present that are promoting more subclinical or clinical ketosis.

Another approach to assessing the herd level risk of ketosis is to look at the ratio of milk fat : protein. Normally, in Holsteins, a ratio ranging from approximately 1.1–1.25 would be considered normal, but in early lactation, due to the mobilization of fat from body stores, the ratio will likely be elevated. When examining the fat : protein ratio, restrict the analysis to cows that are 10–40 days-in-milk (some may go as high as 60 days due to a prolonged risk of subclinical ketosis). Generally, if herds have more than 40% of these early lactation cows with a milk fat : protein ratio >1.4, further investigation is warranted. For more information on the use of milk fat and protein as a diagnostic aid for subclinical ketosis, refer to work by Todd Duffield, et al., at the University of Guelph (Duffield et al., 1997; Duffield, 2000).

4. **Are there mastitis or milk quality problems in the fresh cows starting their first lactation?**

The new infection risk for fresh heifers, defined as percent of animals that are greater than a LSCC score of 4.0 (or actual somatic cell of over 200,000), should be less than 10%–12%. Unfortunately, it is common to see herds consistently above 20%–25%.

5. **Is there any indication of changes in somatic cell count patterns during the dry period?**

A commonly used graph for a quick assessment of changes in somatic cell count during the dry period is a 2 × 2 scatter plot of the first test date LSCC score plotted against the final test date LSCC of the previous lactation as shown in Figure 22.12. The assumption made is that changes between the final test date of the previous lactation and the first test date of the current lactation represent the dynamics of change during the dry period. While this is partially true, it also reflects any change that may have occurred during the interval from the final test date until the dry period, as well as the interval from calving to the first test date of the next lactation.

Four quadrants are shown in Figure 22.12 along with the actual cow counts for each one. The lower left quadrant (D) represents cows that finished their previous lactation with a LSCC < 4.0 and started their current lactation with a LSCC < 4.0. There are 343 cows in this "uninfected" category, representing 64% of the total cows. The upper left quadrant (A) shows the cows (65) that finished lactation with a low LSCC, but at the first test date of the subsequent lactation were above a LSCC of 4.0. This category is called the "new infections" and comprises 12% of the total cows. The upper right quadrant (B) displays the number of cows (34) that were high on both of the test dates. Cows in this category are commonly referred to as the "chronic cows." This group represents about 6% of the

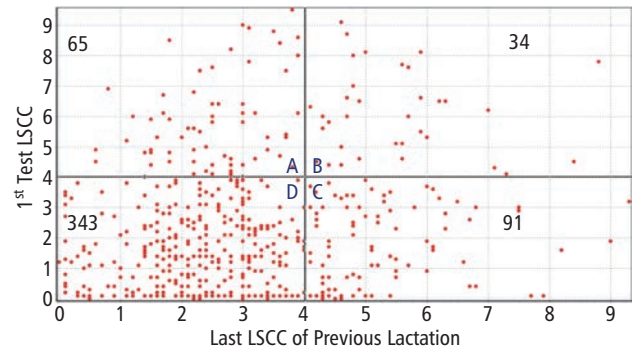

Figure 22.12. A scatter plot of the first test date LSCC score (*y*-axis) plotted against the final test date LSCC (*x*-axis) of the previous lactation. The numbers in each block are an actual count of the cows in each of the four quadrants.

total population. The final quadrant (C) located in the lower right displays the "cures." These cows (17%) were high prior to the dry period and at the first test are now below a LSCC of 4.0.

There are two additional items of interest that can be calculated from within this data. One is called the dry cow new infection risk and is calculated by dividing the number of cows that were less than 4.0 on the final LSCC of the previous lactation but are above 4.0 on the first test date LSCC of the following lactation by the total number of cows that were less than 4.0 on the final LSCC of the previous, that is, 65/(65 + 343) = 16%. The goal for this metric is typically less than 10%–12%. The second commonly used metric that can be derived from this data is the dry cow cure risk. This figure is estimated by dividing the number of cows that were previously high but now are below 4.0 by the total number of cows that were above 4.0 at the final test date of the previous lactation, that is, 91/(91 + 34) = 73%. A goal of 75%–80% is desired.

6. **Does the pattern of early lactation culling suggest any problems?**

A very commonly used metric that is touted to indicate how well transition management is performing is the use of early lactation culling records. The approach that has been suggested by many is that herds should calculate the culling risk (sold and died are often calculated separately) during the first 30 and 60 days in lactation and to use this as a metric for evaluating transition cow management. However, this approach is fraught with issues and should not be used. First, most herds do not calve enough cows to get an accurate assessment of the true point estimate of culling risk. Consider the example shown in Table 22.9 for two different populations, Group "A" and Group "B." Assuming that "A" and "B" are two consecutive months of calving on the same herd, the knee-jerk reaction might be to conclude that something dramatically different happened to the Group "B" animals since the proportion sold during the first 30 and 60 days in milk was numerically double that of Group "A." However, even within these relatively large groups of monthly calvings, there is insufficient sample size to conclude that the true estimates of culling risk between these two populations are different. Assume now that these two populations are different herds. One reaction might be to conclude that herd "B" was struggling with transition cow issues, but in fact, this herd may have a very good level of reproductive performance, have plenty of replacement animals calving, and merely be aggressively culling cows that calve with udder conformation issues, high somatic cell counts, or low milk production without obvious health issues in an attempt to improve the overall herd quality and performance. Thus, the use of early lactation culling is confounded by potentially unknown herd management issues, highly subject to sample size constraints, and really has very little utility within the area of transition monitoring.

Table 22.9. Early lactation culling risk, stratified by sold or died in the first 30 days in milk and within the next 30 days in milk for two populations of cows, Group "A" and Group "B." For each outcome, the actual number of events, the risk for each event and a 95% confidence interval are shown

Event	Total	<30 DIM	31–60 DIM	Total
Group "A"				
Fresh	101			
Sold		4	2	6
		4%	2%	6%
		(1–10%)	*(0–8%)*	*(2–13%)*
Died		3	1	4
		3%	1%	4%
		(0–9%)	*(1–6%)*	*(1–10%)*
Group "B"				
Fresh	88			
Sold		9	3	12
		10%	3%	14%
		(5–19%)	*(1–10%)*	*(7–23%)*
Died		2	1	3
		2%	1%	3%
		(0–9%)	*(0–7%)*	*(1–10%)*

Instead of using culling evaluations, herds should strive to develop better disease treatment and monitoring protocols. If a subset of animals is affected severely enough to require culling, there are also likely negative effects on the remaining population of survivors that will adversely impact production and reproduction. Having a system in place to monitor changes in disease risk (i.e., metritis, mastitis, and displaced abomasum) or risk factors for disease, such as milk fever or retained placenta, allows for more timely and appropriate intervention.

7. **Does the pattern of previous dry period length or days spent in close-up match the management plan?**

Very short dry periods (less than 30 days) may have negative impacts on the subsequent lactation performance. Equally important are the number of excessively long dry periods due to the cost associated with keeping nonproductive cows on the dairy. Generally, excessively long dry periods reflect problems such as

pregnancy loss and rebreeding that results in pregnant cows that are dried prematurely relative to gestational age due to low milk production, technical error either with conception date estimation or data entry into the record system, or management decisions to move pregnant cows into the dry period (rather than culling them) prior to the normal date range due to decreased milk production. Excessively short dry periods are often the result of errors with conception date estimation or data entry into the record system, shortened gestation length due to abortion or premature delivery, or management mistakes (failed to move the cow at the correct time). In general, with weekly pregnancy evaluations in AI herds and weekly moves to the dry pen, a herd should be able to have about 85% of the dry lengths within 14 days +/– of their stated goal. In natural service herds or herds that move cows less often, the variation will be significantly greater.

Another item worth mentioning is the number of days spent in the close-up pen. Most herds move cows from a traditional far dry pen at 21–30 days prior to expected calving in order to modify the ration from a nutritional perspective, manipulate dietary cation–anion differences to manage hypocalcemia, to decrease stocking density and to allow for closer observations. Longer than necessary time spent in close-up is costly and occupies space that other close-up cows may use. Days in close-up of less than 10 may predispose cows to increased risk of periparturient issues. One goal for consideration is to try and achieve at least 10 days in close-up for at least 90% of all cows.

Milk Production Monitoring

The efficient production and marketing of high quality milk is the primary source of revenue for the vast majority of dairies. Reproductive efficiency, transition health and nutritional management all have tremendous impacts on the level of milk production within any herd. Previous sections have reviewed the basics of monitoring reproductive management and transition cow health. A very critical area that has a tremendous impact on milk production and overall profitability is the area of nutritional management, including forage harvest and storage, feed purchase and inventory monitoring, feed delivery, and feed efficiency. While these specific areas will not be reviewed, this section will present a few of the suggested approaches towards monitoring milk production.

Milk production monitoring has many different approaches, and each has its advantages and disadvantages. Traditional metrics like RHA are still commonly reported by many DHIA systems but are of very limited value due to the huge impact of momentum and the inability to detect acute changes, whether positive or negative. As a consequence of these issues, this metric will not be discussed. As mentioned in previous sections, the first step in the records review and evaluation should be to start by asking specific, relevant questions regarding performance of the herd, and then find data to adequately answer the questions posed. Below is a suggested approach towards the monitoring milk production:

1. **What is the current level of milk production in the herd?**

   Milk production pays the bills on the dairy, and all of the other monitoring approaches previously discussed are important because the previously discussed metrics directly or indirectly affect the level of milk produced per cow. However, consultants can often get caught up with test-day records and completely ignore how much milk the farm sold. Consider plotting milk sold per day by the dairy in addition to milk produced per day. Factors that impact milk sold include the number of cows milking, the number of cows in the hospital, and the amount of milk produced per cow.

   a. **Are there any patterns or trends present in test-day milk production (or its derivatives) that might suggest that certain individuals or groups are performing well?**

      Scatter plots of milk production by days-in-milk (with each cow included as a single data point) can be helpful in providing a quick visual assessment of the level of variation in milk across time (days in milk). By adding additional labels (pen, breed, or lactation group 1, 2, or 3+), the scatter plot can now be used to look for trends by pen, breed, stage of lactation, or by parity. However, whenever an evaluation of performance across time is made using these approaches, several precautions are warranted. First, cows that have extended days-in-milk have been subjected to more culling pressure as compared to cows in early to mid-lactation. If culled cow records are missing, a culling bias is introduced, potentially leading to an incorrect assessment that more historical calvings have performed than more recent calvings. Second, there is an implied assumption when examining scatter plot graphs that cows in various stages of lactation have an expectation of similar performance and that they behave similarly across time. For example, cows that are currently between 200 and 275 days-in-milk may be compared to cows that are between 100 and 175 days-in-milk, after adjusting for the effect of the different days-

in-milk. However, one of these groups may have experienced heat stress or overcrowding during the transition or fresh period and be at a significant disadvantage as compared to the other group.

Rather than graphing milk by days-in-milk, a better approach may be to graph milk by calving date so that the observer at least has the opportunity to be reminded of the potential seasonal impacts across time. Another approach that can be helpful is the graphing of week-4 milk and second test date milk (or week-8 milk) by fresh date and by lactation group. Because each test date contains a range of days-in-milk, picking a specific week for a milk production estimate eliminates one large source of variation. Also, those herds that have electronic milk meters might not have monthly test-day data. The use of scatter plots can help to uncover major trends across time and suggest potential seasonal or other impacts, but in reality, this approach should serve as only a starting point that leads to the posing (and answering) of additional questions.

Adding trend lines (usually, simple linear regression lines) across scatter plot data is tempting but can lead to incorrect conclusions regarding performance. As already mentioned, there are inherent confounders present that will impact performance. However, the use of simple linear regression trends lines is potentially problematic due to the insensitivity of this simplistic mathematical approach to fitting a line. Often the fit to the data is poor. Also, within a data set across time, a linear regression line will only show one underlying trend, when in reality, the performance could have oscillated markedly across time.

b. **Have there been any changes in overall test day production?**

Evaluating monthly test-day milk production across time is a common approach many take, but without digging deeper into the potential impact of parity distribution, seasonal influences, or changes in distribution of days in milk, changes in the raw monthly test data do not necessarily indicate progress or failure for the herd.

c. **What percent of milk weights are below some acceptable cut-point?**

Again, similar to the early lactation cut-point analysis, many people like to look at scatter plots of milk by days-in-milk. With this approach, a visual assessment can be made to determine if there are an excessive number of cows with poor starts or if there are any late lactation cows to consider for early drying or culling as a consequence of low milk production. However, scatter plots like these are only the initial inquiry into cows that deserve additional attention. In most programs, the user can click on the point within the scatter plot that represents a cow and learn more about the individual animal. A good approach is to sit with the manager and make sure that they have an explanation for cows below a specified cut-point; for example, cow 236 has mastitis, cow 529 has lameness. While it is not good to have a lot of disease contributing to poor milk production, it is worse to have problems affecting production and not know about it and fail to address the problem.

2. **What is the current days-in-milk for the herd?**

One of the key influencers of average milk per cow at any given point in time is the average days-in-milk for the herd and the distribution of days-in-milk for the herd and by parity. Mature cows typically peak in production between 45 and 75 days-in-milk and then start a slow decline across the remainder of lactation at the rate of approximately 4%–8% per month. First lactation cows peak later, typically between 75 and 120 days-in-milk, and then decline at a slower rate of only about 2%–5% per month. As a consequence, the estimated lactation curves for these two cow groups typically converge around 275 +/− 20 days-in-milk. Average days-in-milk for herds with good reproductive management, nonseasonal calving patterns, and reasonable culling patterns are usually around 160–165. As herds struggle with reproductive inefficiency, days in milk for the herd climbs and average milk per cow decreases. Whenever the level of milk production is evaluated, the impact of days-in-milk must be considered.

3. **Do the mature equivalent milk estimates indicate any problems within parity groups?**

One quick bird's eye assessment of how the parity groups are doing relative to each other is to compare p305me production for parity = 1, parity = 2 and parity > 2. Interpretation of the results must consider the potential that one or more groups is performing poorly, or conversely, that one or more groups is performing better than expected relative to the remainder of the herd. In most herds, the first lactation group's p305me milk estimate will be 2%–5% lower than older cows. Often, people are puzzled by this finding since the first lactation theoretically represents the most modern genetics in the dairy and the expectation is that these cows should produce the most milk. However, most herds do not apply significant culling pressure to their first lactation animals from a milk production perspective, at least not until

later in lactation, and therefore, the p305me for this group will usually include more animals that are genetically inferior. The third and greater lactation group, while representing the oldest genetics, should have a p305me that is at least as good as the second lactation animals or higher since these cows have had multiple lactations of culling pressure. If the performance of the first lactation group is vastly inferior to expectations, potential areas for investigation include frame size at calving, stocking density (especially in mixed parity groups), heifer mastitis challenges, and dystocia challenges unique to the heifers. Common reasons that the first lactation group might be outperforming the other two groups may be related to the purchase of heifers of higher genetic merit, more aggressive culling of heifers due to an increase in supply related to the use of sexed semen, or disease issues in mature cows such as mastitis, metabolic challenges around calving, or lameness. In expanding herds, herds that suffer higher risks for lameness or mastitis, or herds that struggle with reproductive performance, the p305me of the older cows may in fact be 5%–15% less than the second lactation cows. A word of caution is warranted here: marker-assisted genetic selection, that is, genomics or genomic selection, is a new tool that has the potential to dramatically increase the rate of genetic gain in dairy animals. As herds start using genomics-selected sires, these p305me relationships will need to be reevaluated.

4. **How is peak milk production?**

   The evaluation of peak milk by parity group is an approach that has been practiced for many years, but the correlation to overall lactation performance is actually pretty low. In addition, due to the issues of lag, momentum and the difficulties with accurate calculations of an animal's true peak, the use of peak milk is a very poor monitor of transition management and its use should be discouraged. In most systems, the peak milk recorded in the record system is not the true peak (single day's highest level of milk production reached by an individual cow within a lactation), but rather the highest test day milk weight recorded to date. Relying simply on probability estimates, very few cows will actually be tested on their true peak day of production if testing is performed only once every 28–35 days. Also, if an animal has one test that took place at 8 days-in-milk and her milk weight was 42 lb, that is her peak, at least until she has another test date that is higher. As such, there is a need to put some restriction on the days-in-milk in order to more accurately estimate the correct and true peak for an individual cow. One approach is to only look at cows that are beyond some days in milk cut-point such as 60 or 75 days. Another approach is to restrict the estimation to only animals that have a days-in-milk at peak of 45 or more for mature cows and 75 or more for first lactation. In either case, a potential culling bias is introduced since cows that are culled prior to reaching the stated days-in-milk cut-point never contribute to the peak milk estimate. Some animals may not truly peak until later in lactation (beyond 90 days-in-milk). While this is most common in first lactation animals, it also occurs in mature cows and is more prevalent in herds using rBST. As a consequence of the difficulties or confusion around the use of peak milk, this metric should not be used for monitoring. Instead, a better, more consistent, and timelier approach would be to use an estimated milk weight such as week-10 milk or week-10 mature equivalent milk. These two metrics estimate milk production and p305me, respectively, as if the animal had actually tested on her 10th week of lactation. Similar to the previously described week-4 milk, this approach reduces the confusion over determining what the true peak may be, when it may have occurred, and includes less lag.

5. **What about genetics and monitoring?**

   Breeding decisions do not affect milk production for several years, so it is not common to include genetics in routine monitoring. However, the impact is permanent. Appropriate sire selection will impact milk yield.

6. **Culling and overcrowding.**

   Keeping cows too long is a common error in order to have more apparent equity. However, in most farms, the bottom 10% of cows only contribute approximately 3% of the milk. Having 10% extra cows can often have a negative impact on the other 90% of the better cows, due to competition for bunk space, feed, beds, and attention by management. Close monitoring of appropriate pen densities are warranted.

Mastitis Monitoring

Mastitis and milk quality is another important area for monitoring in dairy herds. One of the most common approaches for a quick snapshot assessment of mammary gland health is the 2 × 2 scatter plot approach of plotting current test day somatic cell count (or score) by the previous test somatic cell count as previously mentioned in the early lactation monitoring section. This evaluation requires two sequential monthly somatic cell tests and uses the threshold of 200,000 (or a linear score of 4.0) as the cut-point that divides noninfected (less than 200,000) from infected cows (equal to or greater than 200,000) (Dohoo & Leslie, 1991). The 200,000 somatic

Table 22.10. Mastitis monitoring goals using either recorded cases or a risk classification system based on somatic cell cut-points

Item	Definition	Goals
Monthly incidence risk for clinical mastitis	Proportion of all milking cows each month that are recorded with one or more cases of clinical mastitis	<2.5%
Heifer new infection risk (%)	Proportion of fresh heifers ≥200,000 SCC at first test	<12%
Dry cow new infection risk (%)	Proportion of cows <200,000 SCC at the last test before dry off that calve and have a first test SCC ≥200,000	<12%
Dry cow cure risk (%)	Proportion of cows with an SCC ≥200,000 at the last test of the prior lactation that calve with a first SCC test <200,000	>80%
New mastitis case risk (%)	Proportion of cows that were <200,000 SCC at the previous test but now have SCC ≥200,000	<9%
Cure risk (%)	Proportion of all cows that were ≥200,000 SCC at the previous test but now have an SCC <200,000	>30%
Chronic infection risk (%)	Proportion of cows with 2 consecutive tests that were ≥200,000 SCC at both tests	<15%
Prevalence of infected cows	Proportion of cows at the current test with an SCC ≥200,000	<20%
Chronic cow attributable risk (%)	Percent of current cows ≥200,000 SCC that were also ≥200,000 SCC at the previous test	<65%
Uninfected cows (%)	Proportion of cows that with 2 consecutive tests that were <200,000 SCC at both tests	>70%

cell level has been selected to try and minimize false positive and false negative classification of cows, but there are still cows under 200,000 that have an infection (mastitis) and there are cows over this cut-point that are infection-free, and therefore, this cut-point is not perfect. Based upon the somatic cell count information from two successive tests, cows can be crudely classified into one of four categories based on the 200,000 somatic cell level: (1) new cases, (2) chronic cases, (3) resolved cases, and (4) noninfected cows. Using these classifications, an assessment of the current status of udder health can be estimated from the somatic cell count as shown in Table 22.10. These results can then be compared from previous months and with reported mastitis incidence on a monthly basis.

The 2×2 approach of monitoring mastitis is an attempt to quantify changes in somatic cells in a very objective manner and includes both clinical and subclinical cases of mastitis. However, monitoring the monthly incidence of clinical mastitis is also important. Generally recognized goals for mastitis, defined as the number of cases of mastitis divided by the number of lactating cows at risk, is less than 2%–3% on a monthly basis, or on an annual basis, less than 25 cases per 100 cows at risk. Other important areas for monitoring mastitis include monthly incidence stratified by lactation group, proportion of animals with repeat mastitis cases, and other approaches illustrated in Table 22.10. However, the area of mastitis monitoring goes well beyond the information presented here and readers are advised to refer to additional information published in the field of mastitis and milk quality (Schukken et al., 2003).

Heifer and Youngstock Monitoring

Another key area that should be considered is the area of replacement heifer performance. A full review of this area will not be covered in this text but a few critical questions that should be considered include the following:

1. What is the stillbirth risk (deaths within first 48 h of birth) and does it differ across parity groups?
2. What is the preweaning morbidity (scours, pneumonia) and mortality risk?
3. What is the postweaning mortality risk from weaning to breeding?
4. Are heifers growing (weight and height) at the appropriate rates to reach breeding size at the appropriate age?
5. What is the average age (and distribution) for first service across time?
6. How efficiently are heifers becoming pregnant once they are moved to a breeding pen?

Summary

Monitoring dairy herd reproductive performance can appear to be a complicated, daunting task, but a little

preparation can ensure that the correct performance indicators are used and interpreted correctly. The purpose of monitoring dairy performance through records analysis is to detect change within the production system. In order to accurately detect real change, a structured approach should be used, paying careful attention to issues such as lag, momentum, variation, and bias. Prior to examining records, stop and consider the questions under consideration instead of simply relying on canned reports. The focus of records evaluation for the purposes of improving performance should be on process monitoring as opposed to outcome monitoring. For many people involved in dairy records analyses, this may mean changing the monitoring parameters that have been used in the past. Start by focusing on a few key areas of high importance and dig deeper as necessary.

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23

Managing People in Today's Production Dairy Environment

David P. Sumrall

Abstract

Modern animal agriculture has been reshaped and redefined by technology, economics, and globalization of the industry. This has reshaped and redefined the role of the consulting veterinarian as well. The successful veterinary practice requires the practitioner to be much more than simply an animal doctor. They must be well-grounded in general management strategies, human psychology, and possess excellent communication skills. This discussion examines the key ingredients of management and interpersonal skills necessary for the modern production animal veterinarian to become an indispensable part of the large-herd management team.

Times Have Changed

The face of agriculture has drastically changed during the last three decades. Once dominated and driven by the local family farmer who produced for and sold to a local market, the present-day marketplace is anything but local. There has been and continues to be an evolution of agricultural enterprises of all descriptions and commodities that has redefined modern production agriculture in the United States and around the world. This evolution, though scorned by many as being caused by "corporate farming," is nothing more than a reaction to the reality of the economics of farming in general. Agriculture no longer does business only locally, but is forced to compete in what is now truly a global market. The same dynamics that are driving the evolution of agriculture have occurred in virtually every other business sector of the world economy.

The Greek philosopher, Plato, reasoned that necessity was the mother of invention. Nowhere has this been truer than in the business of agriculture around the globe. As competition from and within global markets has increased, farmers in every country of the world have had to make some difficult decisions. Competing with what is oftentimes cheaper labor and inputs associated with producers in other countries and continents has placed a tremendous demand for efficiency at the farm level, regardless of its location. As an illustration, just as the Industrial Revolution forever changed the way that certain other businesses would operate in the United States, this "agricultural revolution" is having the same impact on the complexion of agriculture around the world.

The brutal reality is that as important as the spirit of the family farm and its entrepreneur is to modern-day agriculture, the size and scale of the traditional family farm as a start-up enterprise today simply cannot compete. Major input costs and ever-escalating production costs simply place an overhead requirement on a beginning enterprise today that forces the business plan to be one of greater size and scale in order to garner enough efficiency to capitalize it, generate sufficient cash flow, and operate profitably.

This evolution has triggered many other areas of change within agriculture. One area impacted the most has been that of general management. Out of the

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necessity to gain efficiency, farms of all descriptions have become larger and in general have required more people to operate them. In most cases, that has meant that off-farm and nonrelated people have been integrated into production operations.

In the traditional family farm, the head of the household on the family farm was in charge of the operation, and may have had one or two hired hands to help with chores that were not serviced by family members. This is changing with the passing of time as the generation of ownership retires. The next generation can ill-afford to pay the previous owner what he should be able to command as a purchase price, because there is not enough scale and production to meet operating expenses as well as service new debt at today's rates. In addition, there is a tremendous amount of competition for the skills and talents of young people raised on the family farm. Off-farm opportunities with significantly larger monetary rewards when compared to historical farm employment beg for the attention of young people, and in far too many cases, win the battle.

With regard to management, the result of the agricultural revolution has been that workforces are larger, and contain nonfamily workers that present the traditional family farmer with a real need for management skills of an entirely different nature than that of managing a smaller family business. In many cases, those skills may require significant development if they are to expand to the caliber required by today's modern production agriculture operation. It is within that need that we will examine and discuss the various vectors and aspects of people management in today's modern dairy enterprise.

Defining Management, Wrestling with Change

In this chapter, we want to explore the role of the veterinarian in today's modern production animal enterprises. There is no question that in evolutionary process that has led to current-day production dairy systems, the role of the veterinarian has drastically changed. We will examine some specifics related to that in detail later in the chapter. First, and to insure that this discussion of management starts from a known and common position, we should first seek to define and explore management itself.

There have been countless volumes written on the subject and at least an equal number of definitions assigned to the word "management." For the purposes of this discussion, management will be defined as "attention to detail." While there are many other more complex definitions that employ much loftier words in their attempt to explain this most important aspect of business, it should be noted that complexity does nothing for increasing understanding. This entire discussion will be predicated on the fact that the simpler a thing is, the more likely it is to be understood and accomplished on a repetitive basis. This basic concept applies not only to defining management but in executing it as well.

There are as many strategies for management as there are situations that require them. Excellent management, by definition, is a dynamic thing. In its highest form, it is ever-changing, adjusting, and realigning itself with the situation at hand.

It has been said that "the only constant is the fact that things are always changing." Change is an interesting thing. The very word strikes fear in the hearts and minds of most people. However, we must realize and assimilate a basic fact; that is, if we are afraid of change, we cannot improve. To declare that change is not necessary is to say that improvement is not needed. Not many people would consciously make such a bold statement, but more often than not, that is exactly what we say with our actions and reactions in the battle of day-to-day work duties and schedules.

Most biological systems like things to be in a constant state. Livestock of all kinds and in particular the dairy cow prefer monotony over variety. There is a reason that cow paths are cut through green meadows. Cows like familiarity. There is a reason why within every herd there is a "boss cow." There is a social hierarchy within all animals that exist in herds or flocks. Changes to that hierarchy have to go through due process to take effect. They have to be properly and effectively communicated. They will inevitably be tested for validity and authority. In many cases, those tests can be brutal and frustrating for all members of the herd. The same is true in the human race, and particularly in the workplace.

Certainly, people are biological systems, and while some may not like the parallelism, in most cases, they are not much different from the dairy cow. In fact, one who is an astute student of the dairy cow can learn much about people and how to manage them simply by detailed observation and thoughtful analysis. The similarities are striking.

People simply do not like change, even when it may be for better. A good manager must be able not only to embrace, implement, and deal with change, but must in fact be a change agent. A good manager is constantly looking for things that need to be changed and for the way to implement that change in a manner that allows it to succeed. Simply put, one of the great distinctions between excellent management and poor management is how change is dealt with in the organization. How is change originated, orchestrated, presented, implemented, and executed? All of these factors will together

determine the reaction to and results of change and, more importantly, the success or failure of a change process.

Change is not a bad thing. As previously alluded to, change is a fact of life. When we are born, the process of change begins immediately, and we will never be the same again. As youngsters, we embrace change. We even thrive on it. We look on new and different things with wide-eyed wonderment. We are eager to learn and try new things. We are observant of even the slightest variation in the world around us and explore every opportunity of each and every new development. We are born almost the opposite of what we become with regard to how we view change. As children, we detest monotony and continuously search and strive to be different. As we grow and mature, ironically, we begin to change. We become entrenched, regimented, and rigid in our approach to life. What once was a challenge or "something new" is now a threat. It is a slow and insidious process, which most of us would deny being involved in if confronted with the facts. Nevertheless, it is an indisputable fact that we and everything around us is in a state of change. Those who recognize and embrace that fact are at a distinct advantage.

Having established the fact that most people do not like change, it is worthwhile to understand the emotions that are intrinsic to a situation of change. They run the entire spectrum of human feeling and emotion depending on the paradigm of the stakeholder. For those that are the most entrenched, change can produce feelings of dread, fear, frustration, intimidation, insignificance, and even anger. On the other extreme, for the individuals who are more change-oriented, those emotions can be just the opposite, resulting in hope, eagerness, fulfillment, and satisfaction. The manager's challenge is to realize that the same set of change circumstances can and often does produce reactions that are just this polar opposite within his team members. The difficulty in dealing with change is the single most frustrating facet of management. Further, change, or rather the lack of dealing with it properly, is one of the leading factors in why many management systems have breakdowns, disappointments, and failures. Entire companies have failed due to their inability to deal with change appropriately.

In the discussion that follows, we will deal with several basic yet specific aspects of people management. It is important that the reader understand that this preceding discussion of change is woven into the very fabric of each and every element of people management and is fundamental to successful management in any arena of life. It is key in the management of one's self, their relationships with others (family, friends, associates), or professionally in the workplace. It applies to all connections within our lives, whether the direction of that relationship is vertical or horizontal. The reality is that we all need change. It is how we improve. It is the lifeblood of management.

The "Six-P" (P^6) Approach to Management

Having already described the process as "dynamic and ever changing," one might get the idea that good management is elusive to the point of being unattainable. Yet, nothing could be further from the truth. Good management in its highest form is relatively simple. True enough, it is a moving target and requires a fluid approach that employs constant adjustment and realignment as referenced earlier, but that does not mean that it has to be complicated. While an excellent management system is dynamic and flexible, it should not and does not have to be confusing.

Within all good management systems there are some common threads that exist that are worth discussing. More importantly, they should be adopted and integrated into the management plan at all levels, regardless of the enterprise that might be involved. They are sound, basic principles that produce the same results every time they are applied, personally or professionally, individually or jointly. These noteworthy characteristics have been dubbed by the author "The Six-P Approach to Management." These six parameters are dynamically interrelated to each other in such a manner as they feed off each other. An improvement in any one of these areas creates a synergistic force with and among the others. It is because of this multiplying effect that the author titles this management approach as an exponential relationship.

P^1—Personnel

The most important resource of any business is its people. Certainly, a dairy enterprise of any size cannot exist or function without the necessary capital, land, facilities, and cattle. However, the most often overlooked resource in the dairy production industry has been and continues to be people. In fact, this historically has been a bigger problem in the agricultural industry than in most other types of business. Part of this lies in the fact that due to a variety of factors, farms are being forced to become larger. As previously discussed, labor forces are expanding, and in many cases, owners are being faced for the first time with the various tasks associated with management, maybe for the first time outside of family ties.

Venturing into the world of labor management for the first time is a formidable challenge and is an awesome responsibility. In the traditional family farm setting, the existence of the family relationship itself makes

the management task very different from that of nonfamily management. The family hierarchy itself establishes levels of authority and a chain of command that in most cases is understood from the earliest years of childhood in most families. This hierarchy carries over into the day-to-day operation of the family farm enterprise. For example, in the traditional family farm setting, the father is in charge, and his authority reigns supreme. The mother is generally second in command. Children on the family farm generally assume positions within the family workforce that are equivalent to their age and competency levels and as importantly, their ability to accept responsibility, operate in trust, and be independently and collectively dependable. As children mature, they assume positions of greater and greater importance within the system.

In the family farm setting, if there is a difference of opinion, there is usually some basis of relationship that allows for some common ground, and the resolution of the problem. Most often, the authority that comes from the family hierarchy itself governs how problems are resolved. Certainly, there can be exceptions to this, but for the most part, children who are of minor age are dependent on the family unit for their very sustenance of life. Food, clothing, and shelter all come from the family business and system, and the dependence that is integral to the child's relationship dictates at least a minimal performance in the chores that are assigned. To a great degree, employees who are family members are bound by family ties and relationships to fit in and be a part of the family outside the home and in the larger arena of the family business. This comes from an innate sense of respect for the family system that in most cases is nurtured and expanded on as we grow up, especially in a family farm setting.

While the traits that we as managers want from outside (nonfamily) employees may be the same (responsible, trustworthy, independently and collectively dependable), these things are not always as prominent or as readily displayed. Off-farm employees may come from very different backgrounds with very different outlooks in life, authority, and performance itself. In today's workplace, they may come from different countries and cultures. Thus, it becomes the manager's job to lead people in a manner that fosters the right kind of attitude in all employees and create an atmosphere wherein all employees have the ability to conform and become a part of a viable, successful team.

Great care should be taken with this most important resource. The time, effort, and resources devoted to employee development are the best investments any business can make in itself. In today's modern dairy farm system with all the complex equipment, tools, and procedures that are a part of it, without genuine support from the workforce, one can throw money at problems until they are out of money, and still not solve the problem. A valuable lesson for every manager to learn is that most problems when traced to their origin have a first and a last name. In many cases, we ask for it. . . . We set ourselves up to fail.

Four Keys to Personnel

There are several things that prudent managers can do to preclude disaster with personnel. Obviously, no system is perfect and there will always be shortcomings. It is important to remember that a management system is a system of people, and there are no perfect people. There will always be breakdowns and disappointments. The trick is to have a system that deals with those shortcomings rather than being consumed by them. There are four very distinct keys to personnel that if properly attended to and executed will reap big rewards.

Locate

A business of any kind must be able to locate the right kind of people. This is easier said than done. As an employer, it is our responsibility to know what we are looking for, and to clearly define the role that this new employee will fill. There is a phrase that says "Location is everything. . . . " It is true in the people management business as well. Know what you want, decide what it is worth, and do not settle for less. It can be a huge mistake to hire an unqualified applicant. The drain on the manager's time to fill in the gaps automatically created by employing an inept employee may outweigh the benefit of having them on the team at all. Know clearly what is required to achieve a minimum level of satisfaction in the position, and hire a person that meets the criteria for that level of performance.

The hiring process should be formalized to include a written application that requires sufficient information to insure that as an employer you have achieved due diligence. There are many resources available to help develop the forms for this process, and all employers should seek professional help with this process, including enough legal advice to make certain that all applicable state and federal laws are observed in the process.

A critical part of the application is a request for references. They should be asked for, and they should be verified. This is one of the easiest and most effective ways to avoid a problem employee in existence, and it takes very little time, effort, or money to do so. It may, however, return great dividends by helping to avoid workers with a previous negative history that is problematic and appears to be patterned in its past.

All applicants should receive a sit-down, face-to-face interview with a qualified and approved person that has training and skills for the interview process. Asking the right questions and being a good listener are paramount in this process. It is important to clearly explain what is being looked for in terms of both technical and nontechnical qualities in the applicant, and they should be able to demonstrate both through their interaction with the interviewer as the process takes place. A written job description should be put in the hands of every applicant and should be thoroughly discussed.

The job description is simply that: a description of the duties of the person filling the position. It should describe the general purpose of the position and the expectations of management with regard to how the employee accomplishes that purpose. The job description is not to be a limiting document, but should describe the minimally acceptable fashion in which the role is to be filled. It should describe as completely as possible the setting and environment in which the employee is to function and should address the expectations of management in clear detail. It is not the role of the job description to list out the specific steps in jobs that the employee is to take. That is addressed through protocols, which we will deal with in detail later. The job description should in summary fashion explain the role of the employee filling the position, and the general approach that management expects the employee to use in fulfilling that role. If there are specific items that are related to the job with respect to special skills or physical requirements, they should be specifically addressed in the job description. If hired, the interviewee should keep the job description as part of their hiring process and for future reference.

One of the best ways to find good people is to be a good employer. Employees and most especially dairy employees, talk to their peers both on and off the farm. Many times dairies are found in clusters, and workers from different farms see and interact with each other in all kinds of social situations. In the process, the subject of work and the working environment will inevitably come up. It is at that moment that the manager wants his people to be able to give a good recommendation to others that are quizzing them about their workplace. If this occurs, good people will find a way to migrate to better positions. The best advice any manager can get is to be the kind of person that one would want to work for oneself.

Educate

Having located and hired the best possible applicant for the job, the employer becomes liable for a number of other things relative to this employee's personal success on the job. "Success" for the purposes of this discussion is defined as a situation wherein the employer and the employee are both happy with the outcome of the new relationship. Probably the most overlooked area of personnel management on the farm today is education. Simply put, most farm owners or managers do not do an adequate job of informing and training workers.

How can you expect an employee to do what you want, the way you want it done, and on your time schedule when you will not even take the time to tell them what it is you want done? Do not dismiss this concept. It happens every day on dairy farms and in milking parlors around the world.

A training program does not mean hiring a "warm body" and throwing them in the milking parlor to learn the procedure by osmosis. To think that any new employee is going to take their job seriously if the owner or manager does not is simply ludicrous. Every discipline on the farm should at a minimum have a basic level training program that clearly communicates (1) what is to be done, (2) how is it to be done, and (3) why it is important that it be done that way. If the training program does not clearly and completely address these three specific issues, then it is of little value.

A formal training program is fundamental to good performance and to the consistency of the operation. In a dairy setting, this is critical. A solid training program that clearly defines the role of the employee, and that teaches them in detail what is to be done in an environment that makes them comfortable to ask why, is critically important. The training program is not a one-time event. Rather, a good training program will involve periodic reviews and refresher courses to keep employees aware of the important role that their job plays in overall farm performance and profitability. Depending on the size of the farm, number of employees involved, and how closely supervision is achieved on a daily basis, the prudent manager will schedule formal training sessions appropriately to keep employees keen in their understanding of their job, and well apprised of how they are doing in relationship to the goals that have been set for them.

Training sessions should be regularly scheduled. This serves as a continual reminder to employees that management takes training seriously, and that it is important to management that employees are well-informed, well-trained, and prepared to perform at levels that are acceptable in terms of general performance. At a minimum, it is good to sit down with employees in a formal group setting at least quarterly. These meetings can be broken up by discipline in most large herd settings today (herd health, calfyard, milking operation,

etc.). This allows the manager to speak directly about issues related directly to those particular employees.

Training sessions do not have to be lengthy. Pick a specific topic that has been observed to be in need of improvement, and spend 20 min in a detailed discussion in an open, conversational approach with employees. Remember, every training session should be centered on what to do, how to do it, and most importantly, why it is important for it to be done as outlined. Employees will seldom purposely perform below par if these three things are truly established by management, and when they do, they are much easier to deal with. As employers and managers, we must recognize and address our responsibility to educate our people.

Motivate

The third distinct responsibility of the manager is to motivate employees. This is a more complex but critical area of people management. Even the best of employees will from time to time find themselves in need of encouragement. Employers and managers that learn this and employ it regularly can and will make the job of management immensely easier.

To be an effective motivator is easier said than done. It is a mixture of science and art to say the least, but it is impossible to fake true motivation. No one can be a good motivator unless they are motivated themselves. People will see right through it. As the old story goes, a chicken can be called "dedicated" to breakfast by providing the eggs. But for bacon to occur, a pig must be "committed." Motivators of people must be committed. They must truly believe in what they are doing, how they are doing it, and why they are doing it. They must truly be excited about their work and the task at hand, and that excitement must come across in a fashion that is sincere and hence believable. As already established, there is some science to the act of motivation, and there are resources to help polish the parts of the motivational process that can be learned. But you cannot be taught to be excited about something. That must come from within. In short, if managers are not truly motivated about what they are trying to communicate, they should not attempt to be the motivator in that particular instance and have the wisdom to pick the right substitute for themselves to get the job done in their place.

To be an effective motivator, the manager must be familiar enough with the employee audience to recognize their needs, and to know how to reach them where they are, and in the way they need. This can be one of the most interesting and fulfilling parts of management. It is one of those areas that allows for the personal interaction between the manager and the employee that when properly approached allows a bond of trust to develop. That bond is a critical foundation on which to build and expand the relationship and achieve the kind of balanced, well-rounded team that today's dairy systems requires.

The object of motivation is to convince people to do the right thing because it is the right thing to do, and to do so with a sense of joy and fulfillment due simply to that reason.

Well-motivated employees do not need much coddling. They are able to enjoy what they do because they feel a sense of pride in what they do. The manager's goal is to provide employees with the kind of environment that provides the opportunity to accomplish their job and be happy doing it. That is not to say that it is the manager's job to make employees happy. Happiness is a personal choice, and every individual is responsible for making the right choices that bring them happiness. What managers must do is provide an environment and opportunity for employees to make the "happy choice." The rest is up to the employee, and this is a key point to communicate clearly and often.

Motivated, engaged managers will find that some of the most gratifying moments of their careers are wrapped up in opportunities that they have had to impact another person's life simply by recognizing their needs and making themselves available to help. It may be nothing more than a willing ear to listen or a ride home from work when their car breaks down. The point is there is no motivation without participation. Managers must participate in the workplace with employees and be an integral part of the daily process. Managers must motivate.

Evaluate

Assume for this discussion that we have accomplished the three previously discussed tasks. We have located the right person, we have educated them properly, and we are doing all the right things to insure that they stay properly motivated. What's left? It is a very important process. We must come up with a method of feedback for ourselves and the employee that affords us every opportunity for improvement. An employee evaluation system is critical. While describing the training process earlier, we questioned how we could expect employees to do the job properly without first telling them what we want to do, how it is to be done, and why it is important to do it that way. In establishing the importance of the evaluation process, we should ask ourselves a similar question. How can we expect employees to know that we are happy or unhappy with their performance unless we tell them so? Further, how can we know if they are

happy or unhappy unless we provide them with a safe forum to express their feelings? The obvious answer to both questions is that we simply cannot.

Two critical principles are involved in the evaluation setting, and they are wrapped up in the phrase "safe forum." "Safe" means that the employee is made to feel comfortable to talk freely in the process and to respectfully express themselves without fear of retribution. The word "forum" implies an open session of learning. That means that everybody who participates has the opportunity to participate and learn something. That includes not only the employee but the manager or employer as well.

There are two types of evaluation. The first is the most obvious and that is the formal evaluation process. We will deal with that presently. The second type of evaluation is most aptly described as "ongoing."

Ongoing evaluation is a day-to-day process. It takes place both consciously and subconsciously in the workplace every day. The good manager makes it a conscious process and is careful not to subconsciously (or even unconsciously) transmit messages to employees that are unintentional.

Most employees are constantly reading their manager. They are looking for signs to help them get a feel for how they are doing. Is the boss happy with me? Am I doing the job properly? Managers need to remember that employees judge by verbal cues, including word choice, tone, or inflection, and the volume of the voice just like everyone else does. Further, they also pick up messages in nonverbal cues as well, such as body language, facial expressions, and eye contact. Managers need to be keenly aware of the messages they are sending in both verbal and nonverbal communications. Often times, negative impressions can be drawn by people around us, even when they are not the target audience. The ongoing evaluation process is as important as the formal process but is an often overlooked area of the personnel side of dairy management. Astute managers know that they can shape and mold their employees in day-to-day interactions that are well-timed and sincere. The actively engaged manager is frequently put in situations referred to as "teachable moments." It is important that in those situations, the employee will always take away a lesson, one way or the other.

No answer *is* an answer. No response *is* a response. No reaction *is* a reaction. Certainly, there are times when it is appropriate to delay an answer, response, or reaction. However, there is a huge difference between doing so on a controlled, thoughtful basis and doing so out of omission, oversight, or just plain ignorance. If a situation occurs in the workplace that needs attention and it is ignored or left unattended to, employees are left to decide if the manager is simply unaware of it, purposely avoided dealing with it, or simply does not know how to deal with it. The results of all three of those scenarios are less than desirable and will place the manager in a disadvantageous light with employees going forward. It can and most likely will affect the way that employees who witness this situation deal with that manager in the future, and, no doubt, they will share their observations and opinions with others. Managers can ill afford to forget that just as they should be constantly evaluating their employees in an ongoing fashion, they themselves are under close scrutiny on an ongoing basis as well. It works both ways. Being cognizant of that fact allows good managers to use it to their advantage.

Formal evaluations are structured events that allow the manager and employee to spend time in a private, usually one-on-one setting. These sessions typically are the least favorite thing of both managers and employees, at least initially and in every case where they are poorly conducted without thoughtful planning. While there is no doubt that there are times when unpleasant discussions must take place in the formal evaluation process, much of the dread that is usually associated with the process is highly exaggerated and manufactured on the part of the manager or the employee or both.

The formal evaluation should be a planned event that is scheduled in advance and becomes a regularly occurring event in the relationship between the manager and the employee. The frequency of the formal evaluation can vary, but in no case should be less than annually. In determining an evaluation schedule, several factors should be considered. Employee turnover is a big consideration. When employee turnover is high, more frequent evaluation sessions are important in order to provide more "quality time" between managers and employees. Another factor in determining formal evaluation schedules is how closely the manager is involved in the day-to-day operation and details of work being done by the employees. In a case where a manager is very "hands-on" with his team and is proficient in executing the ongoing style of evaluation previously described, an annual formal evaluation may be all that is necessary. In larger operations where managers may be multitasking and working across broader areas, it may be important to have semiannual evaluations to offer an opportunity for timely assessment and addressing of specific needs.

Managers should make the formal evaluation as painless as possible. They must keep in mind that this is a stressful time for most employees and should work to make the setting comfortable and allow for an open exchange between themselves and the employee. The manager should put the employee at ease up front. To do so requires some advance preparation.

Here are some tips to help managers get the most out of a formal performance evaluation session:

- **Clear your calendar, and hold the calls.** If the manager expects the employee to take the evaluation session seriously, they must do their part to make it the important process it is. Nothing is more distracting than constant interruptions during a serious meeting. Turn off the cell phone and the farm radio, and have someone else answer the telephone if it rings. The employee should have your undivided attention. Plan accordingly to make the employee feel like the most important matter on your mind during the process.
- **Develop and use a written form for the session.** There are several good forms that are commercially available for the evaluation interview process. It is a good idea to fill out the form in advance of the session, making adequate notes to insure that all issues are properly addressed. This also helps to keep the session on track and avoid straying from the important topics to be discussed.
- **Preview the process with the employee.** Take a few minutes to explain to the employee what is about to happen and why it is important. Encourage employees to ask questions after your explanation to make sure that they understand what is going on. Encourage them to participate.
- **Establish the ground rules.** The purpose of the evaluation session is to give the manager and the employee the chance to communicate with each other. It is a two-way process, and the manager should establish that environment up front. The rules for the process should be simple and should be clearly communicated at the onset:
  1. The discussion is to be confidential. Employees should be made to feel comfortable to speak freely.
  2. Only facts that pertain to the employee's specific performance are to be discussed.
  3. No discussion of the performance or lack thereof of other employees is allowed by either party.
  4. Respectful disagreement from either party is permissible and encouraged when necessary, without fear of retribution.
  5. All issues will be resolved during the discussion or a follow-up session should be scheduled at the end of the process to provide for closure.
- **Tend to business.** Managers need to stick to the subject. Be thorough, but be as brief as possible while being certain to make your evaluation points clear. A little friendly chatter at the beginning of the session to put the employee at ease is fine, but move quickly into the business at hand. Avoid the temptation to wander from the process, especially when having to deliver difficult observations.
- **Respect your employees.** If you have set things up correctly, they expect to hear some critical observations. Most people understand that no human being is perfect, and even the best and most exemplary of employees is aware of things they could do better. If the manager ignores what employees already know about themselves, it will tend to lessen the validity of the discussion.
- **Be prepared to say what you need to say, but to listen as well.** Deliver your message in a thoughtful way, allowing the employee to interact if they feel the need. When they do speak, maintain eye contact and listen intently and patiently without interrupting. If they are brave enough to speak, it is usually for a reason. The sharpest of managers have perfected the skill of listening and asking open-ended questions in order to learn more about themselves, what their employees really think about their management style, and ways that they can improve themselves as managers.
- **Give employees the answers they need.** A critical observation should never be delivered without a suggested course of action to remedy the problem. A complaint without a suggestion for satisfactory corrective measures is almost hypocritical. Further, it solves nothing but only serves to create confusion on the part of the employee. After all, if the boss does not know what he or she wants, how is the employee to know?
- **End on a positive note.** Reiterate the strong points of the employee's performance. Quickly mention the areas that need help and review the plan of corrective measures. Thank the employee for their honesty and candor, and pledge to support them as they work on their corrective measures. Make employees feel comfortable in continuing dialogue and asking for help along the way. This creates an open bond of trust that allows for further constructive discussion and an attitude and atmosphere of continual improvement.

The evaluation process should be viewed as a critical management tool. Properly set up and executed, it will open your mind, sharpen your management skills, revolutionize your outlook on your business, and change forever the way that you approach and treat your employees.

In summary the manager must remember the four key areas of responsibility within the area of personnel:

- Locate
- Educate
- Motivate
- Evaluate

P^2—Purpose

The second principle within the P^6 management system is purpose. Without purpose, everything or more specifically anything would be meaningless. Have you ever stopped in the middle of something and asked yourself what you are doing and why you are really doing it? Have you ever found yourself going through the motions of a task and at some point realized that you were not quite sure of what all the effort was about? We all have. We get busy and burdened by the details of the chore at hand and sometimes forget the real reason for what we are doing. Even at the management level within the organization with the pace that we are forced to keep these days, sometimes we can lose our continuity of purpose. When this happens, confusion sets in and will always give rise to frustration. As frustration grows, motivation deteriorates, and if left unattended, the result is often a sense of utter despair. At the employee level, they will look for a quick fix to this situation and that usually expresses itself first in reduced performance, and later in employee turnover.

It is very important to continually examine purpose. This should be done at all levels and within all disciplines of the organization. What is it that we are really doing? Why are we doing it? Is there a clear purpose for all that we are doing? Has it been effectively communicated to employees at all levels? Good management continually restates and reaffirms purpose. Employees will seldom fail to perform when they know what to do, how to do it, and why it is important to be done.

P^3—Planning

Good planning is fundamental to success. It requires vision and foresight on the part of management personnel. The planning process involves the evaluation and coordination of all resources in a manner that is continuous with the purpose of the organization. It incorporates the effective use of all assets, especially personnel, in a manner that moves the organization or department toward its goal.

Planning should not be done in secret. If employees are to give themselves to the purpose, they must know the plan. More importantly, employees should be a part of the planning process itself. This insures employee involvement at all levels, and will always result in a deeper level of commitment on the part of every involved employee. In short, employees will take "ownership" of a plan that they help to produce.

Planning involves looking carefully at several factors:

- **The job(s) to be done.** As obvious as it may sound, it is critically important to have a discussion with all involved parties about what it is that is being undertaken. This must be a specific, detailed conversation in which every objective of the process is identified and discussed until it is clear to every participant. Most often, it is the obvious that is overlooked and that later creates a problem. This discussion should be thorough and allow ample time for everyone involved to fully understand the specifics. It should include a generous opportunity for everyone to participate in the discussion and to have the chance to get any questions they may have adequately addressed.
- **The sequence and/or timing of the job(s) to be done.** Once the objectives are clearly understood, the detailed steps of the process must be clearly communicated. Again, this is should be a full discussion that covers the most obvious parts of the process as well as the more subtle steps. It should include an explanation of the tasks to be performed, and the sequence in which they are to occur. If applicable, a clear understanding of the timing of each step in the process is important. Again, this discussion should include generous time for questions and answers.
- **The resources needed for the job(s) to be done.** One of the manager's intrinsic duties is to make certain that the necessary inputs for any job are provided. It is unreasonable to expect a person or a group of people to get a job done without the appropriate tools or resources to achieve a satisfactory result. There are three broad categories to consider, discuss, and include:
  1. **Personnel—**How many people are needed for the job at hand? What special talents or capabilities should each person involved possess to make them suitable for the task? Are the people selected sufficiently compatible to work as a team? The manager who knows his people well will be able to avoid many pitfalls that can arise when putting teams together.
  2. **Facilities and/or tools—**This is simply a review of the necessary physical resources that are required to get the job done. Are they available? If so, are they readily adequate for the job at hand? Are there any shortcomings that we need to address with our planning?
  3. **Capital—**Money must always be a part of the planning process. This is especially true in the dairy business. The dairy farm is a capital-intensive enterprise at best, and it is wise to consider the costs of every project or job during the planning process. This is important to do at all levels within the organization. It is a good thing for all employees to understand that the jobs they are doing carry a cost with them. Properly done, this part of the planning process gives all employees a sense of fiduciary responsibility

- **Real or potential shortfalls of resources.** A frank, open discussion of the issues revealed in the foregone discussions of resources is paramount. The planning process is about setting things up for success. Any limitation that is indentified with regard to resources should be thoroughly discussed. Can the limitation be corrected? If not, can it be overcome otherwise? It is important to be clear with this part of the planning process. It makes no sense to start a project knowing that there are resource issues that cannot be overcome. To do so would be to give birth to failure. Work through the limitations and get them satisfactorily addressed or consider postponing the job if possible. There may be times when it is impossible to postpone. In those cases, having had this frank discussion allows for everyone to be aware of the risks assumed by proceeding, and in many cases may lend itself to the resolution of the issues as the project moves forward.
- **The goal or satisfactory end result of the job(s).** Everyone needs to know what success or a satisfactory result is going to look like. This should be clearly communicated so that there is no confusion about what the expectations are of management and what performance level is going to be required by everyone involved to get there.

After a careful examination and open discussion of these factors, a detailed plan should be developed that best accomplishes the objectives, making certain that all resources are being deployed at their best and highest use level. If employees are involved in meaningful planning sessions similar to this, they will take ownership of the task, and give themselves to it in such a way as to insure its success.

If this type of planning is employed at all levels within the organization, the whole becomes greater than the sum of its parts. The synergy of this kind of team approach creates an additive effect to good planning. There are numerous opportunities for this kind of planning to express itself. As an example, if good planning is executed in the maternity lot, then the job in the calfyard just got easier. However, the converse is also true. If you have poor planning in the maternity program, the calf-raising challenge will be much more difficult, no matter how good the planning is in the calfyard.

Good planning is essential at all levels. The phrase ". . . plan your work, and work your plan . . . " is certainly good advice.

P^4—Protocol

No good cook lights the oven without a recipe. A recipe is simply a protocol. It is a detailed description of the step-by-step procedures necessary to accomplish the desired result of the cooking or baking experience. The same is true on the dairy farm. Every major discipline of the dairy farm should have a written protocol. That is, we should provide a recipe to our employees, describing in detail how they are to accomplish their jobs.

A protocol is not to be confused with a job description, which we addressed earlier. A protocol is a detailed "recipe" that describes how to handle specific functions within a job description. For example, herd health is one of the major disciplines in a dairy enterprise. Every employee involved in the herd health program should have a written protocol that details how to handle the major and commonly occurring herd health problems and/or practices. It should clearly spell out what management expects to be done, and when and how it is to be done.

Protocols eliminate confusion and remove doubt or indecision for an employee when faced with a circumstance that requires action. A written protocol "levels the playing field" for all employees. Employees should be keenly familiar with the protocol for their department. They should be given a written copy, and it should be read and discussed in a group setting, allowing for as much discussion as necessary to insure a good understanding on the part of all involved.

Protocols should be circumspect in their detail. They should involve experts where necessary. For example, the veterinarian should be involved in the development of the herd health protocol from beginning to end. Ideally, the veterinarian is the instigator of the process if it is not already in place, and the veterinarian should be the active evaluator of the protocol in an on-going process. The same is true of your nutritionist and a feeding protocol. A milking routine protocol should incorporate professional recommendations, and so forth.

P^5—Practice

Practice is where as they say, "the rubber meets the road." Practice can be defined as the execution of details. It is the day-to-day grind of the chores that make up the job. It is where the fruits of our labors relative to personnel, purpose, planning, and protocols will be evidenced. If we have in fact done a good job of those things, a good "practice" will follow.

It has been said that "practice makes perfect." Not so fast. It is true that practicing something allows us to become more proficient at repeating it with precision. However, that is true of both good habits as well as bad habits. We must insure first of all that everyone understands the right way to do the job and all the steps that are involved. Second, we must make sure that they are "practicing" those proper steps that will achieve the

desired result as opposed to taking shortcuts that produce something less. The attentive manager will always be observing the practices of his people and continually working to improve their execution of details as spelled out in the protocol.

Managers must be aware that employees are continually examining the practices that are performed by their fellow workers. They are also examining the practices of the manager or management team. There is another old saying that says, "Practice what you preach . . ." Management must always remember to do just that. In other words, it is unfair for the manager or employer to expect intense attention to detail, but fail to give the same themselves. Employees will identify this immediately, and will appropriately discount management's influence from that point forward. It is management's responsibility to "walk their talk" at all times, and to require the same of all employees, especially those in supervisory positions. Anything less will eat away at the very heart of the organization and, left unattended, will consume it.

P^6—Performance

Performance is the crowning dividend of our efforts. It is important to insure that performance at all levels is being measured. This is how we can evaluate the previously discussed elements of our management system. If there are specific, measurable goals incorporated into the system at all levels, employees at all levels can measure their own effectiveness.

This system brings its own rewards. If things are going well, employees will be able to see that and will take great pride in the work they have done and the process that produced those results. If results fall short of the goal, employees are completely informed and can be a part of the process in correcting shortfalls that may have caused the goal to not be reached. Oftentimes this process becomes a self-policing one. Employees become "hungry" for success. They will create an unbelievable amount of peer pressure on their co-workers to improve. Employees doing substandard work will feel the pressure and will either change their work ethic and/or the quality of their efforts, or will be dealt with by their peers. This is the ultimate form of employee discipline. It only occurs within excellent management systems.

In summary of our discussion of employee management, good management is a proper combination and balance of each of these six factors within the P^6 approach. To become an excellent manager, one must be willing to become a student of the human race. We must learn all that we can about human nature. We should seize every opportunity to study people. A lot of what we must learn can only be attained by experience. This makes it extremely important for management to become a "good listener." We must remember that we cannot hear clearly when we are speaking.

Management, like many other things is life, is an extension of our attitude. We should recognize that attitude is the single most important factor in our work, our relationships, and for that matter our lives. It affects everything we do or say, and it controls the impression that results within everyone with whom we come in contact. Our accomplishments will fade long before the result of our attitude. It is this author's opinion that attitude is more important to success than anything.

The Consulting Veterinarian

Now that we have thoroughly discussed management in general together with some specific requirements and approaches, let us focus more specifically on the role of the veterinarian within the management framework of the modern production animal facility. Just as the role of the modern dairy owner and manager has changed, the role of the veterinarian has evolved as well. Historically, and even today in smaller operations, the veterinarian is the herd doctor, hence more likely to be focused on individual cows he or she has been called to diagnose and treat rather than interfacing into a complex management system that involves a large workforce departmentalized into different disciplines and teams. It is a very different setting that requires a very different approach. It is still very much a veterinary medical practice that directly impacts the health and well-being of the production animal, but it is the way in which that must be accomplished that is vastly different from working in a small farm setting. That is not to minimize the importance of the small farm or the veterinarian who serves it. It is simply that the approaches in the two cases are different and must be dealt with differently. This discussion will focus on the veterinarian's role in the large-herd dairy enterprises that are becoming increasingly more common in production animal medicine today. This is evident in the fact that the veterinary profession itself has recognized the distinction in coining the phrase "consulting veterinarian." This name alone implies a very different relationship from that of the veterinarian of decades ago.

First and foremost, the consulting veterinarian must have a good fundamental understanding of management, which is the justification for the preceding detailed discussion. This is critical, as veterinarians in today's large dairy herd system occupy just another position on the team and, as such, must understand how to integrate themselves into that system in a manner that allows

them to become a productive member of the management team. Being effective as a veterinarian in this setting is dependent upon one's ability to infiltrate the system, which may vary widely from one farm setting to another. The existing approach to management may be misguided, inept, or simply nonfunctional. On the other hand, it may be very well organized and effective. Either way, the consulting veterinarian plays a large and important part in the success of the overall operation. The trick is to be able to evaluate the current system, develop an educated and accurate assessment, and then formulate the best approach in which to insert oneself into the existing scheme in order to have the greatest value to the operation.

It is important to point out that depending on the hierarchy of the management team, this approach could vary greatly. For example, in some situations, the owner is in fact the manager. In others, the owner may be of absentee status or present but not directly involved in operations. The manager may carry a host of different levels of authority, depending on the owners' wishes and design. The owner and/or the manager may have areas in which they carry great expertise, but others in which they are severely lacking. To be of the most value to the operational team and hence the profitability of the dairy, veterinarians must be able to read the people and personalities involved and must possess enough diplomacy to position themselves in a manner that allows them to contribute at a high level.

The technical skills that veterinarians acquire and develop through their long years of study are clearly important. However, unless the veterinary student understands just how critical the art of communication and diplomacy are, chances are very good that early results in practice are at best going to be highly frustrating. Just as the scalpel is a tool in surgery, so are good communication skills to the consulting veterinarian in today's large-herd setting.

Many Hats, Multiple Roles

The consulting practitioner in the large production animal setting today must wear many hats and play many various roles to be effective. As previously stated, the technical studies and associated skills are important but are only part of the equation in delivering meaningful veterinary programs to modern animal agriculture today. In addition to excelling in those technical skills, the most valuable advice this writer can give is to use every available elective hour in some form of human skills study. This may seem insignificant to you the reader, but upon entry into the world of practice it will become abundantly clear.

It is important to remember that if all the employees in an operation were plotted on a graph regardless of the trait being examined, in most cases the graph would resemble the notorious "bell curve." In the course of practice, the veterinarian will encounter people from every extreme of the curve, and must be prepared to deal with each of them. There is no choice in this fact; the veterinarian must be able to work with all kinds of people. This is true in the case of all levels within the hierarchy of the organization, including owners, managers, supervisors, and other employees.

As an example, let us look at only one human trait, commonly referred to as "motivation." If there were a way to test and score the degree of motivation possessed by an individual, we already know that those scores would range from very low to very high, with the bulk of the scores falling in the mid-range area, thus creating that bell-shaped curve. This is not any different from the dynamics that as a student you have no doubt encountered in a variety of your other studies that are riddled with statistics. The critical piece for veterinarians to understand is that this same dynamic is in play with every person with which they must engage, and with a host of factors that affect job performance.

In many cases of the veterinary world, you will be forced to work with "averages." They are used to evaluate techniques, study or measure progress, and as a guide for planning. But within the complexity of human relationships, this approach simply does not work. In the vast majority of our human encounters we must deal with one person at a time, and on any given day, those people are at varying points along that bell curve depending on a huge variety of other factors over which we have no control or perhaps any knowledge of at all. The workplace is a complicated menagerie of all types of people with all types of personalities, all ranges of emotions, and all ranges of work ethics.

To illustrate the importance of this concept, let us return to our example of the trait we call motivation. Is it easier to teach a person who is highly motivated and eager to learn? Of course it is. Is every employee on the farm highly motivated? Of course they are not. Is it likely that the approach to teach a less motivated employee is different? The answer is obviously but unequivocally "yes." The point here is that the veterinarian must be prepared to deal with all kinds of people, each with their own personality, emotions, and work ethics. Adding to this mix are the additional dynamics that are associated with interacting with the various and different levels within the management hierarchy. Interacting with the owner of the business requires a different approach than with a manager in the operation. Likewise, interacting

with that manager requires a different approach than with his reports.

Successful consulting veterinarians are students of the human race. They must be part psychologist, part teacher, and part coach. They must in each role be well-versed and sincere. And above all, they must be great communicators. They must have patience, and they must know when to force issues and just how much pressure is enough. They must be able to work alongside people they like and dislike, as well as people that like or dislike them. They must be able to recognize and work with people at all levels of intelligence, understanding, and skill without compromising on a minimally acceptable level of performance at the very least. It goes without saying that the successful consulting veterinarian must possess and display the kind of attitude and work ethic as that which he or she expects from others.

Teaching Is Essential

The consulting veterinarian on today's dairy farms is as much a teacher as anything else. Dairy farms that consist of thousands of cows that are milked around the clock are busy places. In many cases, there are employees that have had a variety of levels of training and experience, some of which have been formal while other parts have been "trial by fire." The need for training may or may not be recognized by ownership or management, and given the host of other issues that are being dealt with, even when recognized may not take the priority that it should. This is a key factor for the consulting veterinarian to assess and an equally key role for the veterinarian to play. In essence, the veterinarian can become the key driver for the animal health education program, second only to the owner or manager's motivation level in this regard.

The value of a veterinarian in the large-herd setting today is not measured by his ability to successfully perform left-displaced abomasum (LDA) surgeries, deliver a calf in a breech presentation, or miraculously save a milk fever case with an intravenous drip of calcium. Clearly, those abilities are important, and initially are a surefire way to get a relationship started on the farm. However, to become the valuable veterinary asset that is the most satisfying for the owner or manager and veterinarian alike, the veterinarian should develop programs to teach the dairy team how to avoid those LDAs to begin with. He or she should be able to deliver an effective dry and maternity cow management program that reduces the need for those late night ambulatory calls for malpresentations. They should be able to assist the team in learning how to avoid conditions such as hypocalcaemia, whether it is clinical or subclinical. In short, today more than ever, the herd health program is and should be about prevention rather than cures.

The point is that the consulting veterinarian on today's dairies is of more value teaching the team to avoid costly conditions that require the performing of complex surgeries or other expensive technical responses. There will be enough of that even when the team is well educated and performing at its peak. The goal of the veterinarian should be to maximize the herd health and productivity of the operation by multiplying his or her training and expertise through others. It is much the same concept as described in that saying, "Give a man a fish, and he'll eat for a day; teach a man to fish, and he'll eat for a lifetime."

There is great value to the dairy owner and manager of veterinarian-driven training sessions. In the first place, by definition the veterinarian is recognized as an expert. Second, the astute dairy owner or manager understands that lectures or lessons they have been repeatedly frustrated in trying to deliver to their own troops may fall on much more receptive ears when coming from an off-farm expert. It is a dynamic that is many times hard for the owner or manager to understand, but is very real just the same. At the end of the day, the smart owner or manager is happy to gain the benefit regardless of where it comes from. The consulting veterinarian earns the respect and allegiance of owners, managers, and employees alike when skillfully employing this technique.

Large-herd owners or managers are busy people. They have little time to waste in the course of their day, and their time is very valuable to the business. The most successful consulting veterinarians have a keen understanding of this and let it drive their approach to the overall effort in delivering their herd health expertise to the operation. As discussed earlier, the consulting veterinarian is a teacher. Like any other educator, he or she must develop a meaningful "lesson plan" that incorporates a comprehensive coverage of the key disciplines on the dairy farm. As no one person can be an expert on every subject, it is important for veterinarians to know their own strengths and weaknesses as these relate to the different disciplines on the dairy and to plan accordingly. It is crucial to remember that the real value of the veterinarian to the operation is the sum of the advances made in overall herd health. Whether that advance is made from teaching delivered directly by the veterinarian or through other resources he or she may engage should be irrelevant to the veterinarian. To successfully deliver the comprehensive teaching program being described here requires the veterinarian to possess enough self-confidence to engage those resources, enough leadership to guide them in their assistance to the program, and enough trust in the ownership and

management that they will understand and properly credit the veterinarian's role in the process.

It's Not All Fun

There is no way around to evade the reality that if the consulting veterinarian is as engaged in the team approach to herd health management as he or she should be, sooner or later there will come a time when the difficulties of people management and relationships will come to bear in a real and tangible way. Every employee is not a joy to work with. There will be difficult employees, and they will produce difficult circumstances for everyone, including the consulting veterinarian. There will be times when conversation will be witnessed or actions will be observed that are less than exemplary, and in some cases the veterinarian may be the only person in a position to witness or observe them. When these instances arise, it can be unsettling, and one must be prepared to deal with that.

To begin with, the best time to set standards is at the onset of a relationship. In the first visit to the farm, an air of openness and honesty should be clearly established. The reality is that in a majority of the time, people tend to deliver what is expected of them. If the consulting veterinarian clearly lays out their approach, complete with what their expectations of others are, the stage is set to minimize the pain of personnel difficulties when they do arise.

The best approach for dealing with adversity of any kind is to do so honestly. This will depend on the exact nature of the relationship, but is advisable in every case. The veterinarian must walk a fine line as they work with the employees of the operation. They need to be able to command respect, but must do so in an atmosphere that does not inhibit honesty or openness. There will be times when the consulting veterinarian will have to deal with unacceptable behavior of employees. It is important to remember that the employees work for the company, not for the veterinarian. Getting the proper result in corrective action depends heavily on the relationship that exists, the chain of command within the organization, and the level of empowerment that the owner or manager has given to the veterinarian. This should be very clearly understood by all in order to avoid disastrous results.

Veterinarians must take great care to avoid having their effectiveness compromised by anyone within the organization. Regardless of where it comes from, it cannot be good for business, either the business being served or that of the veterinarian. Potential compromises may be caused by anyone within the organization, from the owner to the newest employee on the farm. As has been discussed in other issues previously, the veterinarian must be prepared to deal with each of these circumstances in its own unique way as they may arise.

Most often, these situations are caused by being caught up in conversations with people who are simply having a bad day. It is easy to get caught up in such conversations simply by making an effort to be understanding. Avoiding trouble means being continually vigilant. There is an art to knowing when to let someone vent and when to stop the process. It is always best to stop the process if it is merely gossip or hearsay. Otherwise, one will find themselves in the no-win position of having to take one side of an issue or another. Stay focused on the team approach to preventative veterinary medicine, and stay above the fray of organizational politics or employee banter. Anything less will demean your success and minimize your positive impact on the program.

There is an old saying that, "The boss may not always be right, but he is always the boss." The veterinarian must deal with this reality. If you practice long enough, you will run into the uncomfortable situation of having an employee put you in the position of disagreeing with the person that signs your check. For all the obvious reasons, this needs to be carefully handled. One should never do or say anything that appears to be subversive or undermining to the owner or manager in charge. Any conversation that is in any way critical of an owner or top management should be with those people directly and behind closed doors. In every word and deed, the consulting veterinarian needs to be supportive of ownership and management. If something arises serious enough that the veterinarian cannot be supportive of ownership and management and the problem cannot be resolved, then it is obvious that a business decision must be made. However, there is never anything to be gained from venting inappropriately.

The consulting veterinarian's most important role is to maximize the health of the herd in the most cost-effective manner. However, and in addition, he or she is also in a unique position to influence ownership, management, and the general population of employees in a very positive way. This is best accomplished by initially setting the relationship up to succeed by laying the ground rules out for all parties and clearly defining how the veterinarian's role is to be intertwined within the fabric of the organization.

The most desirable situation is for the veterinarian to be free to be honest, open, and above all, objective in their interactions with all levels of people in the organization. Properly executed, this approach allows the veterinarian to be free of the encumbrances that go along with organizational politics. It should be said at this point, however, that this situation will not spawn itself in most cases. It is up to the veterinarian to set things up

in this manner at the outset of the relationship. It will take some work, but it is work that is worth doing, and may in fact be the most worthwhile effort of all, given the fact that the whole mechanism of delivery of an effective comprehensive herd health system is dependent upon the consulting veterinarian's ability to get things done through other people.

Closing the Gate

The role of the consulting veterinarian when done well is much more than just practicing animal medicine. As pointed out more than once in this text, as critically important as it is for the veterinarian to be deeply schooled in the complex biological systems of animals, that knowledge in and of itself is of lesser value unless the veterinarian possesses the interpersonal skills to communicate with people at all levels of their own knowledge, understanding, and experience. Delivering an effective animal health program in the production animal arena requires the veterinarian to be as much a manager as anyone within the production system. He or she must be able to communicate at the ownership level, the highest levels of management, and with every level of employee in the system right down to the newest and most inexperienced employee in the system.

Throughout this text, communication has been stressed as a key element of a successful management program. This is an equally important ingredient of a successful production animal practice. There is simply no way around the fact that the consulting veterinarian must be a balanced mixture of animal doctor, teacher, coach, psychologist, salesman, and perhaps in some cases, a politician as well. The ability to blend the right mixture of these roles to fit the moment and in so doing deliver the right message in the right context is an art to be sure, but it is not as complicated as it may sound. However, it must come from the heart, or even the flashiest of presentations will fall on deaf ears. In practice, the veterinarian will work with people of all levels of intelligence and education, but it will always pay to remember that even the most uneducated of people can sense insincerity and will discount the message, whatever it may be.

The most important tool in the consulting veterinarian's bag is his or her own passion for their work. Working with large production animal operations today can at times be the most frustrating job in the world. Conversely, at those special times when things come together and the message is properly delivered, comprehended, and implemented to produce the desired results, it can be the most satisfying. In short, the consulting veterinarian's role is not for the faint of heart. Fundamental to his or her success is a burning passion for animals, a genuine love of people, and an insatiable desire to make a positive difference in the lives of both.

24

Practical Genetics

Donald Bennink

Abstract

The ideal dairy cow should be long lived, high producing, and trouble free. However, there are varying opinions as to how to meet this goal. The compromise opinion with the highest level of acceptance became that if we bred for production and type at the same time, the desire for high production with longevity would be met. The new trend toward improving health traits and the giant strides that genomics will bring about to help this will result in major differences between modern artificially inseminated sired cows and natural service bull sired cows. This will increase income per cow per year. This chapter discusses practical application of genetics via artificial insemination (AI) to correct the mistakes of the past. Priorities will be placed on breeding productive, long-lived, highly fertile individuals that adapt to modern dairying by low levels of problems with maximum profitability.

Introduction

Everyone agrees the ideal dairy cow is long-lived, high-producing, and trouble free. How to meet this goal has had highly recognized individuals with dramatically varying opinions. This varied from many, particularly in the academic community, saying the "highest producers will naturally stay in the herd longer because they won't be culled for low production" to the super cowman saying the secret to success was "breeding for type and feeding for production."

The compromise opinion with the highest level of acceptance became that if we bred for production and type at the same time, the desire for high production with longevity would be met. This was the dominant opinion 50 years ago and may still be at the time of this writing.

The success in increasing production in the major dairy breed or breeds has been nothing short of phenomenal and is shown in Figure 24.1. Note how the bull population and the selection of artificial insemination sires for this trait dragged the cow population up.

Much the same became true in the industry's efforts to improve type as illustrated in Figure 24.2. Note the substantial increases in overall type, udders, and feet and legs as measured through Holstein's classification system.

Yet look at what happened by following what we were taught:

- Herd life has dropped as shown in Figure 24.3.
- Mortality has gone up as shown in Figure 24.4.
- Somatic cells went up as shown in Figure 24.5.
- Daughter Pregnancy Rates went down as shown in Figure 24.6.
- The number of calves born alive at 48 h as a percentage of cow inventory decreased from 93.4% in 1996 to 86.0% in 2007 (NAHMS Population Estimates—D. Heifer Health, 2007).

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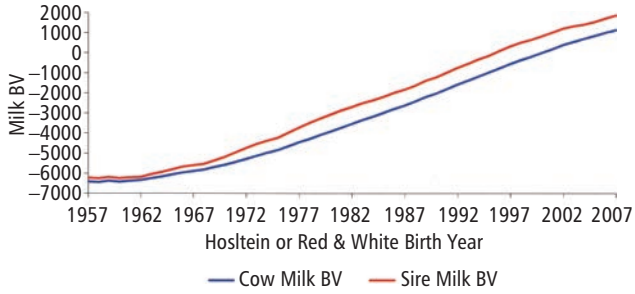


Figure 24.1. Milk for Holstein or Red and White Cattle. *Source*: aipl.arsusda.gov/eval/summary/trend.cfm.

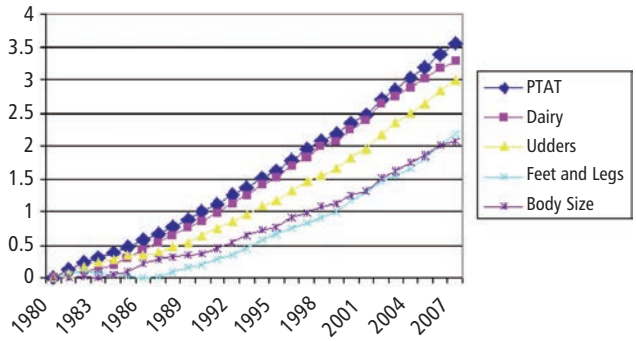


Figure 24.2. Overall type, udders feet, and legs as measured through the Holstein association classification system from 1978 to 2008. *Source*: Dr. T. Lawlor Holstein Association.

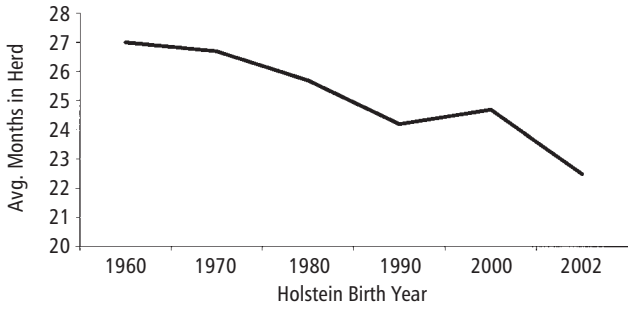


Figure 24.3. Herd life over time. *Source*: USDA AIPL.

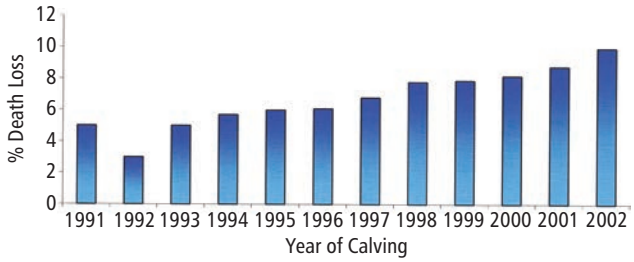


Figure 24.4. Cow mortality rates. *Source*: DHI Provo data. Tripp. 2004.

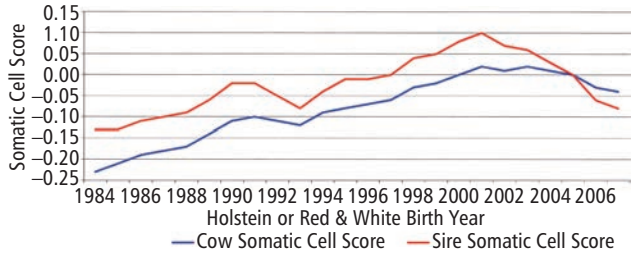


Figure 24.5. Somatic cell score for Holstein or Red & White cattle. *Source*: aipl.arsusda.gov/eval/summary/trend.cfm?R_Menu=HO.s#StartBody.

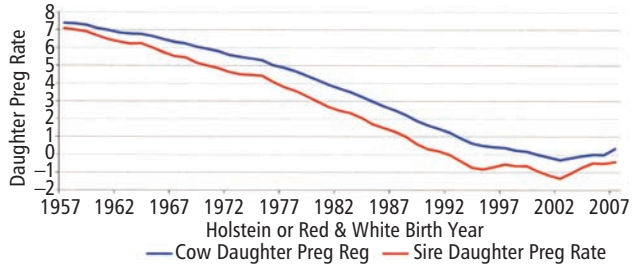


Figure 24.6. Daughter pregnancy rate for Holstein or Red and White cattle. *Source*: aipl.arsusda.gov/eval/summary/trend.cfm?R_Menu=HO.d#StartBody.

Management or Fitness Traits

The people in the industry that are trying to rectify the errors of the past are largely pointing their genetic programs toward what is known as the "health traits," sometimes called "management traits" or "fitness traits." The measureable health traits that are available to the dairyman as of this writing are:

- Productive Life often abbreviated as PL.
- Somatic Cell Score abbreviated as SCS.
- Fertility or Daughter Pregnancy Rate abbreviated as DPR.
- Calving Ease of both the calves the bull sires, known as Sire Calving Ease (SCE), and how easy his daughters calve, known as Daughter Calving Ease (DCE)
- Stillbirths

PL has gone through a number of transformations. The PL number represents the number of months above or below the average herd life for the breed.

The number used for *SCS* (uses a base of 3). Animals below a 3 have a lower than average SCS for the breed and those above a 3, a higher than average SCS. Low SCS being desirable.

Pregnancy rate (PR) is a term used to define the percentage of animals in the breeding herd that become pregnant within a 21-day period. DPR is the percentage

above or below the average PR of the breeding group they are part of.

Say we have a bull with a DPR of 3.0. Also assume that the breeding groups they are part of average a PR of 15. That means the PR of that bull's daughter's averages 18.

Stillbirths became a serious problem in Holsteins as a result of some very popular bulls either directly siring calves that were born dead and/or siring daughters that had stillborn calves.

The Holstein Association has available a list for Type and Production Index (TPI) that is used to rank bulls. Many people make their sire selections from the list. At one point, 7 of the top 10 on this list had a sire whose first calf daughters had 21% dead calves. Most of that bull's sons also sired high stillbirth levels. The problem was exacerbated by a failure to release this information to the industry both on this individual bull and the slowness to release a watered-down version of stillbirth data on all bulls. As a result, bulls carrying this highly undesirable characteristic polluted the Holstein population. In addition, many bull mothers were daughters or granddaughters of the worst culprit.

Due to the health trait problems that evolved, many dairymen lost faith in genetics. Some that had used AI went back to natural service bulls. The Holstein cow gained the reputation as a cow that liked to die. In certain circles, one black and white calf was worth as much as another. In desperation, some went to crossbreeding even though the large population of Holsteins still had considerable genetic diversity.

Correcting Mistakes Made in the Past

The balance of this chapter is largely devoted to how to correct the mistakes of the past. Priorities will be placed on breeding productive, long-lived, highly fertile individuals that adapt to modern dairying by low levels of problems with maximum profitability.

To give some idea of the economics and importance of PL, Figure 24.7 is a bar graph developed by Dr. Nate Zwald. This represents the number of cows remaining in the herd at various numbers of lactations or fractions thereof from calving 1000 heifers with different average PL sires. The dollars and cents difference between calving heifers whose sires have PLs of –2.7 are average or are +2.7 is immense. Note that after 1.5 lactations, there are 200 more cows remaining in the herd from the plus 2.7 versus the negative 2.7 PL sires. At a replacement cost of $1500 per head, that is $300,000. That is without considering the following:

- Less mastitis
- Less discarded milk
- Lower somatic cells

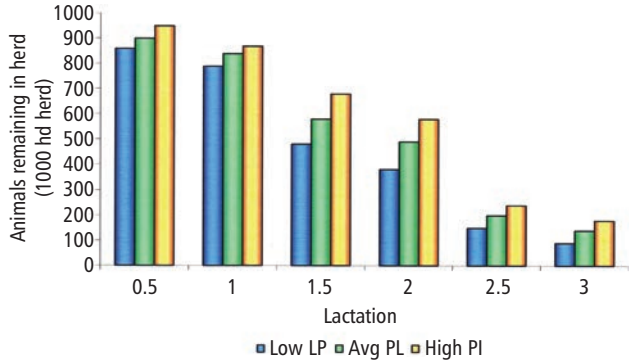


Figure 24.7. What does increased productive life mean? At the end of the second lactation we would need 200 less replacements for every 1000 cows. Based on low = –2.7 PL bulls, avg = 0.0 PL bulls, high = +2.7 PL bulls November 2004 Evaluation run. *Source*: Dr. Nate Zwald.

Table 24.1. Genetic correlations of traits with longevity

Daughter pregnancy rate	0.59
Somatic cell score	–0.35
Udder	0.30
Daughter calving ease	–0.24
Sire calving ease	–0.19
Feet and legs	0.19
Size	–0.04

Source: aipl.arsusda.gov/.

- Less breeding problems
- Less drug and veterinary bills
- Smaller hospital herd with resulting lower labor cost
- More calves on the ground
- Fewer calving problems
- Less semen and breeding supplies
- Fewer dead cows
- Fewer stillbirths
- A much better herd genetically for profitability

In reality, the decision made on the sires of that group of 1000 heifers could easily be a half million dollar decision.

As shown in Table 24.1, the correlation of Daughter Fertility or DPR with PL is the highest of the individual traits. The first calf heifer may have a beautiful udder, high production, and lots of eye appeal, but if she will not breed back, what good is she?

One of the pet peeves of the author of this chapter is the overemphasis of the term heritability by many geneticists. Not only because the number can be very inaccurate, but also because the emphasis has resulted in many of the problems previously addressed.

Generally, heritability is defined as the percentage of a particular characteristic that genetics controls relative to that portion affected by environment or management. The heritability of fertility in dairy cattle has often been cited to be as low as 4 (Seykora & McDaniel, 1982). This resulted in many dairy cattle breeders saying that at that low a number, why pay attention to a bull's daughter fertility. Yet successful beef cow-calf producers feel fertility of females is highly heritable and give key emphasis to the trait.

In a discussion with a well-respected geneticist at the United States Department of Agriculture, he acknowledged that the difference in heritability between herds was substantial. If you have a herd using poor quality semen, poor breeding technique, no heat detection, poor nutrition, and little or no observation or veterinary care, the heritability is 0. A cow, no matter how fertile, has no chance of becoming pregnant. This gets averaged in with the well-managed herds that show a major difference in PR between their highly fertile and their infertile cows.

In our 4000+ cow herd, the fertility difference between daughters of high DPR bulls and the daughters of low DPR bulls is substantial. As you view Table 24.2, of the chart by Dr. Dan Webb (University of Florida, College of Agriculture, Department of Animal Sciences, Gainesville, FL), observe the following two points.

Table 24.2. Conception rates by sire DPR group—North Florida Holsteins

DPR range	DPR group	No. cows	Avg. Preg Per Serv
All lactations			
2.4+	1	167	34.86%
0.0 to 2.3	2	740	29.21%
–0.1 to –2.3	3	630	27.64%
–2.4 and below	4	109	23.04%
Lactation = 1			
2.4+	1	85	35.41%
0.0 to –2.3	2	420	35.12%
–0.1 to –2.3	3	220	26.16%
–2.4 and below	4	15	18.99%
Lactation = 2+			
2.4+	1	82	34.31%
0.0 to 2.3	2	320	23.93%
–0.1 to –2.3	3	410	28.51%
–2.4 and below	4	94	23.86%

For cows coded Preg in PCDART as of March 26, 2008. Source: Dr. Dan Webb, University of Florida, 2008.

1. For first calf heifers, the conception for high versus low DPR sired cows is nearly twice as high.
2. For second and more lactation animals the conception rate for the high DPR sired cows is 50% higher.

Although not thoroughly analyzed, the impression is that the gap is closed between first and later lactations because such a high percentage of daughters of low DPR bulls are culled because they will not breed back after their first calf. This means they are not in the pool to lower the conception for the low DPR sired animals in second and later lactations.

Another way to look at this is a very common PR for many herds not only in the South and West regions of the United States, but also other areas, is 15. As stated earlier, DPR for a bull is how he compares percentagewise to the other animals in the breeding herd. That means if we use the 15 PR and we have two bulls, one with a 3.0 DPR and the other with a –3.0 DPR, the PRs would be expected to be 18 and 12, respectively. With 18 being 50% greater than 12, it fits the numbers found in our herd.

The economics of a 50% higher PR or conception rate is substantial. This would have a major effect on herd turnover and overall farm bottom line.

With mastitis being one of the major reasons for herd turnover, plus drug costs, death loss, dumped milk, and loss of somatic cell premiums in some markets, any genetic connection is important. The literature cites studies where the bulls siring the lowest somatic cells and lowest mastitis incidence have only about half the number of mastitis cases as the very high incidence bull's daughters (Steine, 1966; Heringstad et al., 2000; Nash et al., 2000).

The incidence of clinical mastitis and the numbers of clinical episodes per lactation may be reduced by selection for lower somatic cell score, longer productive life, shallower udders, deeper udder cleft, or strongly attached fore udders (Nash et al., 2000).

The Nordic countries (Denmark, Finland, Norway, and Sweden) are the only countries with well-established, national recording systems for health data in dairy cattle and the only countries that include clinical mastitis directly in their breeding programs. Within this environment, Heringstad et al. (2000) concluded that the accuracy of selection and hence the potential gain from selection for low mastitis incidence can be quite high, especially when the progeny group size is large (Nash et al., 2000).

The industry is well aware of the major economic effect of lameness on the dairy industry. This is a major factor whether it be primary or secondary, to the loss of many cows, much production, and lots of body

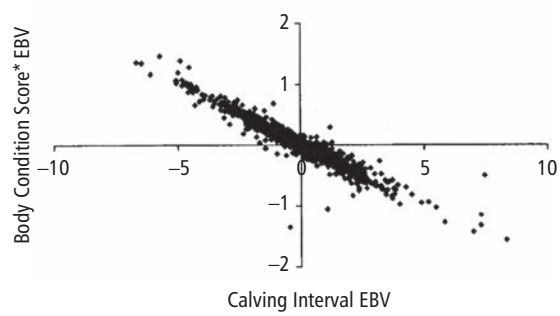
condition. The primary analysis for Holsteins has been the Foot and Leg Composite as developed by the Holstein Association through its classification system. This is a visual rating given by the Holsteins' classifiers according to their training as to what a foot and leg should look like.

The Nordics took another look at the ideal way to analyze foot health as a result of their experience with recording systems for health data. This time the Swedes took the lead. The first international report to the production side of the industry was in *Holstein International*. Here they gave the research and/or opinions of researchers H. Slathammar, J.A. Ericksson, and C. Bergsten. Swedish hoof trimmers were taught to record hoof disorders in a consistent manner. Almost 20,000 cows were recorded per month. As quoted from *Holstein International*, "Sole ulcer accounts for 50% of the breeding value, because of its high economic and welfare value; sole hemorrhage and heel horn erosion for 20%; and (inter) digital dermatitis for 10%. Cows with a severe lesion have a higher weight in the calculation than a cow with a mild lesion." These numbers are used to form an index.

The author of this chapter's review of the bulls listed with Hoof Health Indexes in *Holstein International* showed that the highest indexes went to what were the highest or among the very highest PL bulls with major daughter numbers in the United States. There was very little, if any, correlation with United States Foot and Leg Composite and the Swedish Hoof Health Index. Should the inferences from the Swedish study prove correct, major corrections need to be made in the United States system if cow health, welfare, and dairy economics are important. This may just be another case of too many people sitting behind a desk deciding what a cow should look like. One time or another, that system has been a disaster to every species of farm livestock.

As previously shown in Table 24.1, DCE and SCE have substantial correlations with longevity or PL. Anyone with much time around a dairy farm is aware that hard pulls, dead calves, metritis, retained placentas, c-sections, and down or dead new mothers are not desirable. Prior to accurate data on Calving Ease and DPR, our friends behind the desk were everyone's authority on the subject. Much verbiage was used to describe the ideal rump. Eye appeal carried the day. Those of us on the farm have figured out decisions were being made in reverse. What a rump looks like should be based on calving ease, fertility, and mobility not on what someone thinks it should look like.

The show ring can have surprising effects on livestock selection. In dairy cattle, I find that many of my friends who are well-known fitters for shows are also judges.



* Body condition scores were measured on a 1–9 scale.

Figure 24.8. Body condition score versus fertility, 3770 Holstein sires in the United Kingdom. *Source*: Dr. Kent Weigel, University of Wisconsin.

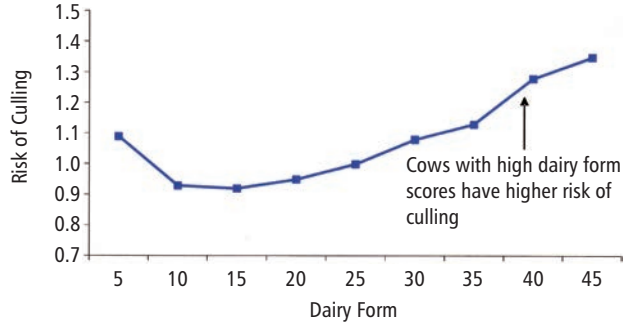


Figure 24.9. Dairy form versus survival for U.S. Holsteins. *Source*: Dr. Kent Weigel, University of Wisconsin.

This group has a tendency to compare one animal to another by mental rules or gauges. Yardsticks become tools of choice. As a result "bigger," "taller," "sharper" have become major reasons for putting one animal over another in a class. The commercial dairyman needs "stronger," "tougher," "more resilient," "durable."

Two examples of longevity and fertility being tied to the ability to hold body condition are shown in Figures 24.8 and 24.9. It has become common knowledge that thin cows and cows losing weight do not breed back. Cows that hold their body condition and still milk are becoming the modern kind for those of us who count on our cows to pay the bills.

The balance of this paragraph is taken from a paper presented by Dr. Kent Weigel at The National Genetics Workshop in honor of Dr. Ben McDaniel, October 20–21, 2003 (Weigel, 2003). Several studies in the United States and Europe have identified a significant relationship between high scores for dairy character and impaired fertility or increased incidence of metabolic disorders. The message is becoming quite clear—cows with

extreme dairy character lack adequate body condition and suffer from impaired health, fertility, and survival. At best, visual assessment of dairy character is redundant. Why does a farmer need someone to look at his/her cow once in her lifetime to see if she looks like she gives a lot of milk—he/she can get daily, weekly, or monthly milk weights from the parlor or DHI supervisor? Breed associations should stop rewarding this trait in their selection indices and type classification programs.

Corey Geiger, one of the editors for *Hoard's Dairyman*, says it best when he says, "We can still look for dams and sires whose daughters are milking hard and don't show it. If we don't believe we can achieve this, then we don't believe in milk records." (Geiger, 2003).

Chad DeChow says, "We can conclude that, at a given level of production during lactation, the cow with more body condition will remain healthier and be more reproductively fit" (DeChow, 2003).

Two studies reported in 2009 by the *Journal of Dairy Science* pointed out the effects of body condition score on foot health and udder health. Bicalho et al. (2009) reported some of the most enlightening and interesting research that those of us interested in healthy, happy cows have come across. There is a cushion in the bottom of the foot that provides protection to the bottom bone in the foot known as the third phalanx. The researchers developed a method to measure the thickness of the digital cushion in live animals. The thickness of this cushion is directly related to cow's body condition. They found the prevalence of sole ulcers and white line diseases were significantly associated with digital cushion thickness. Cows with low digital thickness were at a higher risk of claw horn lesions. Such contusions are a consequence of the lesser capacity of the digital cushion to dampen the pressure exerted by the third phalanx on the soft tissue beneath. The udder health study reported by Van Straten et al. (2009) stated that greater negative energy balance in early lactation predisposes dairy cows to udder inflammation. Considering the fact that many of the events were recurring, they stressed the importance of including all events in the analysis and postulate the possibility of long-term detrimental effects of negative energy balance on udder health.

When the evidence overwhelmingly points toward the importance of maintaining a medium or moderate level of body condition for maximum fertility, survivability, foot health, udder health, and profitability, it is time for the proponents of sharpness to surrender.

The mating of related animals has been intentionally practiced for centuries. The terms inbreeding and linebreeding have been used somewhat interchangeably. When used together, inbreeding generally means the mating of close relatives whereas linebreeding is bringing animals together from the same families, but more distantly related.

In the scientific community, the term inbreeding is measured by using an index. As Seykora and McDaniel (1982) state in a *Dairy Herd Management* article, "The degree to which an individual is inbred is measured by its inbreeding coefficient which is one-half the relationship of its parents." They go on to state that if an animal has common unrelated ancestors from both its sire and dam that the combination is added to the inbreeding coefficient. To take two modern bulls for an example: If a particular heifer's sire is a Shottle from an Oman and her dam is an Oman from a Shottle, the inbreeding coefficient is the common relationship of Oman plus Shottle, not just either one of them individually.

Various forms of linebreeding or inbreeding have been practiced by both the breeder on the farm and the scientist. Sometimes practices that are somewhat of a muted version of corn hybrid genetics have been practiced. That is the mating of two separate inbred lines.

The dairy cattle breeders of the past developed herds around a bloodline with the purpose of developing a premium market for their cattle. Famous Holstein bloodlines included the Rag Apples, Burkes, and Dunloggins. These sometimes developed into subbloodlines like the Tidy Burkes or the Pabst Burkes. Various levels of inbreeding were used from very intense to more subdued depending on the philosophy of the breeder. In the eyes of many, these bloodlines were actually a genetic "brand" that you could purchase for herd improvement. This at first was largely bulls and an occasional female. Technology later allowed this to be semen and then embryos. The scientific community got into the act, intentionally or not when the Animal Model came into being. This computer model was designed to intensify what the designers of the model felt was the very best genetics available. Some pretty intense inbreeding was the result. Big increases in production resulted along with enormous health trait losses. This was because the formula did not waste space on what were considered traits with low heritability.

Another result of inbreeding has been the intensification of undesirable recessives. The two best-known ones in Holsteins have been the lethals, CVM (complex vertebral malformation) and Blad (bovine leukocyte adhesion). Other dairy breeds with smaller genetic bases have had serious problems from undesirable recessives. Our friends in the beef world have seen some real popular bloodlines collapse as a result.

Inbreeding, particularly intense, is not for the faint of heart. There are some pretty remote chances of high levels of success. For the average dairyman, his goal

should be to keep inbreeding to a minimum. There is still enough variety in Holstein genetics to do this and maintain quality.

Dr. Bennet Cassell in the March 25, 1998 issue of *Hoard's Dairyman* states, "Inbreeding reduces health, fertility, vigor and productivity in dairy cattle." He goes on to emphasize that the results of inbreeding will increase embryonic deaths and calf mortality plus decrease growth rates and fertility. This results in longer calving intervals, depressed production, and a lower productive life.

So what do you do when you want better livability, higher fertility, improved calving ease, more disease resistance with lower herd turnover and death loss? Many feel the answer is crossbreeding. A leading advocate of crossbreeding is Dr. Les Hansen. He cites the 6.5% gain from heterosis or hybrid vigor as a major reason to go this direction in addition to higher fertility and overall improvement in the health traits (National Dairy Genetics Workshop, 2003). Eliminating concern for inbreeding is cited.

Dr. Peter Hansen (Hansen, 2007) in reviewing the research of Dr. Les Hansen (Hansen, 2003) on crossbreeding Holsteins and others concludes as follows:

- Crossbreeding takes advantage of heterosis (improved performance of offspring over the average performance of parents).
- Crossbreeding can improve fertility and longevity at the expense of a decrease in milk yield.
- Loss of heterosis and loss of uniformity of offspring are possible.

From a practical standpoint, maintaining heterosis with three- or four-way breed crosses requires as much bookwork as a registered purebred herd. If you do not know the parentage and breed order in the pedigree of every animal, you cannot consistently maintain whatever hybrid vigor might be possible. For instance, if the intended order of parentage is Holstein, Jersey, Swedish Red, Brown Swiss, one needs to know where each animal is in that order so you know what breed of bull needs to be used on her.

With a breed like Holstein and possibly Jersey, there is a wide enough potential pool to allow picking from the top 5% or 10% of the population for health traits. This writer found an extreme lack of information available in the previous decade or two, but the data are available today to make major management trait progress.

Reviewing the graph in Figure 24.10 shows the difference in progress on daughter fertility by crossbreeding and ignoring DPR versus using the best DPR sires. Note the heterosis kick in the first generation followed by the steady progress from the use of high DPR sires after that.

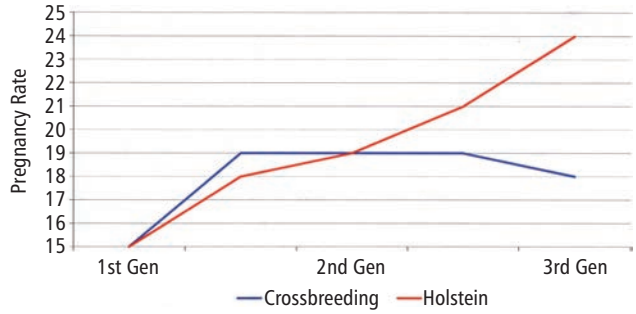


Figure 24.10. What about crossbreeding? Fertility will not increase in the long term. *Source*: Dr. Nate Zwald (2007).

The use of genomics should only improve this as will be related later in the chapter.

The point is that with the extreme selection of fitness traits from a large population and keeping inbreeding in control, considerable advantage in these traits plus much greater production should be the result. This applies to most management styles used in the United States.

Places where crossbreeding has the most long-term potential for milk production is with extreme climates or extreme circumstances. An example would be in countries with very hot humid climates and high insect and disease pressure. Crossing high-producing dairy breeds with their low-producing, but disease- and insect-resistant native cattle could be beneficial.

With the advent of sexed semen, another potential for crossbreeding exists. Breed the top portion of the herd to sexed semen for whatever number of females the dairyperson desires and the balance to a preselected beef breed that will produce a consistent uniform feeder calf. As of this writing, the national beef herd is the lowest in 50 years, and the feed lots are only at 58% capacity. What might work is for specialized growers picking the calves up at a week old (like veal calf growers and heifer calf growers do now) and raise large numbers of crossbred calves so they can be sold in truckload lots to back grounders or feedlots. The ideal cross is whatever makes up for the Holstein weaknesses of large bone size, low feed efficiency, and lack of overall toughness that the packer and feed yard would appreciate. There might even be a cross that would cover for the present worthless Jersey bull calves. This would also cover some of the controversy of excess dairy females creating surplus problems. The average value of the beef cross calf could easily be worth as much or more than the average value of 50% dairy heifer calves and 50% dairy bull calves.

As Dr. Tom Lawlor, geneticist for the Holstein Association, said in his paper Genomic Selection, intended for general distribution to Holstein Breeders, "Genome is a fancy word for all of an animal's DNA. So, genomic selection is using the animal's DNA

information to predict its genetic merit and then selecting the best animals based upon that prediction."

Dr. Lawlor goes on to say, "Geneticists are now able to genotype your animal, identify which exact set of 54,000 genetic markers your animal inherited, sum up all of the plusses and minuses associated with that unique set of genetic markers and predict your animal's genetic merit."

From our very first lessons in genetics, we were taught that we receive half our genes from each parent. As we learn to read genetic markers, this statement becomes, "on the average we receive 50% from each parent." Melvin Tooker (Tooker, 2009) with the United States Department of Agriculture points out that full siblings are expected to share 50% of their DNA on the average. They may actually share 45% or 55% of their DNA because each inherits a different mixture of chromosome segments from the two parents. Because we can read at least some of these differences, reliability can increase if genomics is used to replace traditional relationships.

Dr. Kent Weigel, in an article dated August 21, 2008, titled "Genomic Selection—A Practical Explanation," made points as follows:

- For a young Holstein bull or heifer, we can combine the animals Parent Average with information from the Bovine SNP50 Bead Chip to get a genomic PTA (Production Type Average).
- The reliability as a result of only Parent Average is typically only 30%–40% whereas this increases to 60%–70% with the genomic PTA.
- For a heifer calf, reliability of its genomic PTA is equivalent to that from measuring several lactation records on the animal and its daughters.
- For a bull calf, reliability of its genomics PTA is equivalent to that obtained by measuring performance on about a dozen daughters.
- Once this bull completes progeny testing and has performance data from 80 to 100 daughters, information from the Bead Chip has relatively little value.

Dr. Tom Lawlor, in another article for Holstein Association membership published in the summer of 2008, titled "Update on Genomic Testing," made a few other points. The chance that an AI organization would pick the correct bull calf when choosing between full siblings went from 50:50 to 71% with genomics. Holstein Association and University of Minnesota jointly completed a trial showing that the genomic reliability of health traits is high.

A reason for, but not a criticism of, a limited number of females being genomically tested is the U.S. $250 cost. The writer splurged and has tested nearly 140. That is probably more than any other individual dairy farm. Very possibly, this pool of females included many individuals that were genetically substantially different from the pool of bulls used to locate the genomic markers for the calculation of relative values for the various criteria evaluated. Part of this difference is that at the time the bulls were sampled, health traits were not in vogue, but the writer was on a management trait kick in his breeding program. Another discovery was that for each public reporting period for genomic results, the numbers are adjusted. Individuals with initial disappointing genomic results can end up eventually meeting expectations as relatives and progeny become part of the tested proof.

Emails from Dr. Kent Weigel and Dr. Paul Van Raden give verification. Kent says, "Genomic PTA's are likely to be more accurate for the popular families than the unique families." Paul says that predictions are less accurate when fewer close relatives have been genotyped to estimate the values of their chromosomes. This causes their published genomic reliabilities to be lower.

The future of genomic testing is substantial. As the technology is perfected, new uses will become standard. Even at the current early stages, more accurate decisions can be made in animal selection and mating. Mistakes can be avoided such as being aware that an exceptional individual is genomically high for somatic cells when her Parent Average indicated she should be low. This should improve the quality of matings and thus enhance genetic progress.

Even though the technology of embryo transfer and genomics were introduced to the dairy industry several decades apart, their potential to enhance each other is more than substantial. A real case of where the sum of the whole is greater than the parts. Embryo transfer has advanced dairy genetics substantially. The cost factor has kept it away from most commercial producers. Genomics may help.

One of the real costs of embryo transfer is flushing the wrong animals, those that are not genetically superior. Previous attempts to jump generation intervals have had limited success as a result. This is where young heifers have been flushed (even sometimes to young sires) with the idea they could be genetically advanced over their parents. These hopefully superior young animals then hopefully bring even further advancement when combined. Genomics should eliminate a lot of the guessing and substantially increase the chances of locating and combining the superior individuals. This increase in percentage of superior individuals should reduce the cost of producing said superior individual.

For the individual wanting to produce larger numbers of advanced females, several options exist. This would include flushing the genomically superior heifers mated to sexed semen from superior bulls and placing the

embryos in animals of a level below those chosen to flush. Of the options available at the time this is written, this is the lowest cost method to put superior quality female genetics on the ground.

Many in the industry, including the writer, tended to flush a large percentage of higher producing older cows because they had proven to have health traits by their own survival and maybe have some quality progeny. The problem is this decision is largely phenotypic rather than genotypic. The individual cow may have done well, but she may not have the genes to transmit. Major decisions might be made on the basis of two, three, or four daughters. We would not give a bull any credit for a four-daughter proof, yet we tend to make major decisions on an individual cow based on that data.

In the past, major mistakes were made by choosing bulls for AI from females who never had more than one natural calf. We know nothing about this female's longevity, disease resistance, fertility, tendency to get mastitis, and other economically important traits. Hopefully, flushing genomically superior females for production, DPR, somatic cells, and PL will overcome the problems of the past.

There are a number of systems that attempt to mate each individual cow to the bull that best fits them. They essentially divide into two systems, linear and coded. The linear systems break down to correspond with the classification system of the various breed associations. The coded systems specify a designation for various body shapes and characteristics with a goal of achieving balance rather than extremes.

The linear system matches bulls with cows that need improvement where the bulls are strong as determined by classifiers. The cows should be strong in areas where the bulls are weak. For instance, a bull that sires high and wide rear udders but weak fore udders would be used on cows with rear udder problems but have strong fore udders.

With the coded systems, part of one code includes udders with quality that have wide rear udders, need some shape; tend to be shorter fore uddered with longer teats. This would be matched with the code of the opposite sex that includes shapely udders with shorter teats needing quality but having longer fore udders and tend toward narrowness of rear udder. Coding is more a grouping of traits versus the individual trait versus trait of linear.

The linear systems are generally marketed by the AI organizations and the coded systems by private companies or individuals. The AI organizations do furnish the codes on their bulls for people who wish to use the coded system. Pete Blodgett made major contributions during his life to both systems. His background as a breeder, classifier, AI bull stud manager, bull buyer, and private breeding consultant more than qualified him. To many in the industry, his cow knowledge, pedigree recall, memory for cows, insight, and desire to help made him the best "cow man" they ever knew.

Having had the good fortune to spend many days and hours with Pete for the two decades prior to his death in late 2008, my respect for him had a significant effect on my personal philosophy of mating cows and breeding cattle. Private conversations with Pete showed he had major concerns with linear mating from his experience as a classifier and from his many years of observing classifiers and the results of their work. Big, deep bodied first calf heifers tended to be overrated for their strength, and smaller, rounder heifers tended to be called weak when they really were not.

Dr. Les Hansen wrote an article titled, "What Should a Functional Cow Look Like?" that was published January 9, 2006. The article was part of the proceedings from the Red Cow Symposium 2005 that took place in South Africa. In the article, he goes over the various trends in breeding Holsteins and the effects of these trends on their longevity. Considerable verbiage is devoted to work at the University of Minnesota where two lines of Holsteins have been bred since 1966 with one line devoted to using current active AI bulls that were known for small size and another line that evolved from current active AI sires known for large size.

Among Dr. Hansen's conclusions from the article are the following:

- Dairy producers should not attempt to overcome deficiencies in heifer growth by selecting sires for larger mature body size. If heifers lack adequate body size, factors other than genetics almost certainly are the causes. Cows that are bred to be larger continue to grow more after first calving than cows that are bred somewhat smaller. Once a cow reaches optimum size, continued growth beyond that size is not economically desirable and is detrimental to survival.
- Only traits that are documented to increase productivity and efficiency should be included in selection goals. Udder depth, foot angle, somatic cell count, cow fertility, calving ease, and survival are examples of traits known to impact profitability of milk production.
- Over the long term, selection for traits with documented positive impact on profitability should result in cows of optimum appearance. Moderate-sized cows with less sharpness (and udders held well above the ground) are the most likely to survive the longest in dairy herds in most places in the world.

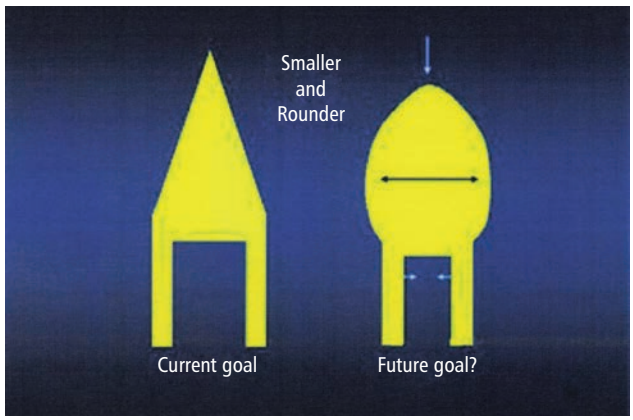


Figure 24.11. A return to the original prototype. *Source*: www.milkproduction.com/Library/Articles/default.htm.

I want to go to back into the heart of this article to show what Dr. Hansen has explained in the best manner I am aware of. Most of this will quote him directly rather than paraphrase because I do not want to take away from the quality of his effort.

Figure 24.11 has the silhouettes of two cows from the front view. The cow on the left has been the ideal of the Holstein breed since 1977. The cow on the right has the silhouette that research suggests will have the optimum performance in dairy herds in most environments around the world at this time. The cow on the right is not as tall, is not as wide on the chest floor (nor as wide in the rump), but she is wider through the shoulder region than the cow on the left. The cow on the right has flesh and muscle in the shoulder region from which to draw reserves to aid fertility and health; however, the cow on the left has little but bone in the shoulder region.

An argument provided by registered Holstein breeders is that cows need a wide chest floor to provide for heart and lungs. The heart and lungs of cows do not hang between their front legs! (Author—If I can do the unusual and one-up Dr. Hansen on this one, he should have said "Has anyone ever known a butcher or a pathologist who found a cow's heart and lungs in her brisket?") Mother Nature made cattle to look more like the silhouette of the cow on the right. On the other hand, the silhouette of the cow on the left is a tall front ended cow with "uphill run," which creates a pinched body area where the neck connects to the 10 body. The silhouette of the cow on the left resulted from registered breeders' selecting for cattle they thought were pleasing to look at. However, a smarter approach would be to allow cows to tell dairy producers what cows need to look like to be functional.

Today we never see large swine, chicken (egg or meat), or turkey producers that do not have a very specialized genetic program as a core of their success. Many of the very largest dairy herds in the United States that make a major portion of the milk in the country have a genetic base of jumper bulls. Ownership and management do not feel there is a financial advantage to following the genetic programs that are offered.

I feel this came about as a result of the two major choices of AI sires being from two extremes. One was the group that had the philosophy that we could build maximum profitability by breeding for production and ignore health traits. The other is a group that bred for eye appeal and also ignored health traits.

The guy in the trenches trying to put as much milk out the driveway as he could and pay the bills had no input. The dairymen listening to the Pete Blodgetts in the industry and demanding practical, functional cattle have shown the AI industry that if they are going to compete, they are going to have to listen to the customer who will produce the most sales.

The AI companies tend to look at the other AI companies as their major competitor and getting business from the other guy is the way to gain market share. In reality, the jumper bull is their biggest competitor and their biggest opportunity.

The new trend toward improving health traits and the giant strides that genomics will bring about to help this will result in major differences between modern AI sired cows and jumper bull sired cows. This will be hundreds of dollars per cow per year. This is a big opportunity for AI and a big opportunity for dairymen to improve efficiency. You do not find a profitable corn, chicken, turkey, or swine grower who does not use advanced genetics. Soon the same will be true for dairy producers.

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25

Euthanasia Techniques for Dairy Cattle

Jan K. Shearer and Jim P. Reynolds

Abstract

Concern for assuring the welfare of animals in livestock production has increased our interest in the subject of euthanasia. It is simply the right thing to do when slaughter is not a viable option and pain and suffering cannot be adequately managed by medical means. This chapter is intended to address a variety of issues with respect to euthanasia of dairy cattle, including physiological mechanisms of death, indications for the procedure, methods and their application, determination of death, personnel training, and other considerations.

Introduction

Owners of livestock assume certain responsibilities, among them are requirements to provide food, water, shelter, protection from predators, medical care as needed, and a humane death. While most of these tasks are intuitive to caretakers of livestock, one that is not is the need to be equipped and be able to perform euthanasia when necessary. It is never a pleasurable chore, but in some cases is the only practical way to provide prompt relief of otherwise uncontrollable animal pain and suffering. To that extent, it is a responsibility of all who own or work with livestock to have the proper equipment and knowledge to conduct this procedure with maximum efficiency and effectiveness.

The veterinarian's role with respect to euthanasia varies according to their clients' comfort level in conducting this procedure. For dairymen with a close emotional attachment to their animals, the veterinarian is the person they call on to perform the euthanasia task. For larger operations where day-to-day care for animals is the responsibility of employees, euthanasia may be the chore of a worker assigned to the hospital area. In the latter situation, the veterinarian's role is more likely to be that of a trainer of these procedures. Since employee turnover rates and procedural drift are inevitable, training and monitoring of personnel assigned these duties are important activities in the implementation of comprehensive health programs by veterinarians. Finally, decisions about the need for euthanasia are not always clear-cut. Prognostic information from a veterinarian is often essential to aid in the decision-making process where euthanasia is an option. So, while the roles of veterinarians may differ, their involvement in euthanasia decisions is fundamental to assuring the objective of a humane death.

Euthanasia Defined

Euthanasia means "good death." It is accomplished when death results in a minimum of pain, fear, or distress to the animal. The avoidance of pain and emotional distress requires the use of techniques that induce an immediate loss of consciousness followed by cardiac and respiratory arrest that ultimately results in loss of brain function. For persons performing euthanasia, a certain degree of technical proficiency, knowledge of anatomical landmarks, and appropriate equipment are required.

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The reality is that the situations whereby a person may be required to perform euthanasia are frequently on-farm. In some cases, it is an emergency procedure perhaps associated with some type of traumatic event. In others, it is a decision based upon one's assessment of a sick animal's locomotory status, prognosis for recovery, or perceived suffering. Regardless of reason, for the sake of the animal and its caretaker who may also be the person required to perform the task, the ability to induce both a rapid and humane death are of paramount importance.

Physiological Mechanisms of Death by Euthanasia

Death may be induced by one or more of the following mechanisms: direct depression of the central nervous system (CNS), hypoxia, and/or physical disruption of brain activity. Direct depression of the CNS is most commonly achieved through the intravenous injection of barbiturates. Though not commonly used in a livestock production setting, inhalant anesthetics such as ether or halothane (or possibly, other inhalant anesthetics) will also induce death through depression of the CNS; however, they have significant human safety concerns. Hypoxia, or lack of oxygen, is achieved by exposing animals to high concentrations of gases such as carbon dioxide or argon, or through rapid blood loss (exsanguination). Gunshot, blunt force trauma, or captive bolt stunning devices induce death by physical damage to CNS which results in a disruption of brain activity. Death normally occurs as a result of respiratory and cardiac failure.

Recognition of Pain and Suffering in Animals

Uncontrollable pain and suffering in cattle are primary indications for euthanasia, but these are easily misinterpreted. Prey animals instinctively avoid expressions of pain in order to evade the notice of predators. Cattle, for example, may simply become less responsive or depressed and lame animals will adjust their gait or posture to mask evidence of lameness. Predators, on the other hand, freely express signs of pain or discomfort. Consider the reaction of a dog that has inadvertently had its foot stepped on. The response is verbally loud, its flight reaction swift, and on occasion punctuated by aggression. This is an important distinction, since failure to conduct euthanasia procedures in timely fashion is sometimes related to a misinterpretation of an animal's response to pain and suffering. Experience and education of the animal handler are important prerequisites to the accurate assessment of animal behavior, particularly when it is necessary to distinguish distress from normal behavior.

Indications for Euthanasia

The loss of productive function that may result from disease or injury offers at least two options: slaughter or euthanasia. Slaughter should be considered for animals that are *not* in severe pain, freely able to stand and walk, able to be transported or moved, and without disease or treatment that might constitute a public health risk (such as drug residue). Euthanasia is the appropriate choice when these conditions cannot be met and/or when the animal's quality of life is compromised beyond repair.

Examples of conditions which would justify euthanasia include the following:

- Fractures of the legs, hip, or spine that are not repairable and result in immobility or an inability to stand
- Emergency medical conditions that result in excruciating pain that cannot be relieved by treatment (trauma associated with highway accidents)
- Emaciation and/or debilitation from disease or injury that may result in an animal being too weak to be transported
- Paralysis from traumatic injuries or disease that result in immobility
- Cancerous conditions—lymphoma and squamous cell carcinomas (cancer eye) of cattle
- Disease conditions for which cost of treatment is prohibitive
- Disease conditions where no effective treatment is known (Johne's Disease in ruminants), prognosis is poor, or time to expected recovery is unusually prolonged
- Chronic disease where treatment is unlikely to improve outcome (chronic respiratory disease in cattle)
- Rabies-suspect animals—where there is a significant threat to human health

Animals with CNS symptoms should be handled carefully. Owners should be counseled to avoid killing these animals by gunshot or other methods which result in head trauma that might cause excessive damage or loss of brain tissue leading to an increased potential for human exposure to the rabies virus. Instead, rabies-suspect animals should be attended to by a veterinarian who can properly euthanize the animal and obtain the necessary tissues for diagnostic purposes.

One of the biggest challenges is determining—*how long should an animal be given to recover?* Evidence of improvement may include frequent attempts to stand and a continued interest in eating and drinking. Animals

that refuse to eat or drink, prefer to lie on one side (rather than roll from side to side), and resist efforts to stand are not good candidates for recovery. Depending upon the specific disorder encountered, most animals will exhibit evidence of a positive response to therapy within 24 h. Rarely do animals recover when they do not show progress within the first 36 h following treatment. Recovery time for animals that experience injuries may be more prolonged and harder to estimate.

Whenever the outcome of disease or injury is in doubt, a veterinarian should be consulted for advice. Simply leaving an animal that is suffering to die of natural causes or, in other words, "letting nature take its course" is *unacceptable*. Furthermore, it is *not* acceptable to prolong an animal's misery by delaying euthanasia for reasons of convenience (i.e., waiting for the veterinarian's weekly visit). It is important that when euthanasia is indicated, it should be conducted in a timely manner.

Nonambulatory Cattle

Some of the best candidates for euthanasia are nonambulatory cattle. The incidence of nonambulatory animals based upon nonfed cattle reports from federally inspected plants during 1994 and 1999 were between 1.1% and 1.5% for nonambulatory dairy cows and 0.7% to 1.1% for nonambulatory beef cattle (Smith et al., 1994, 1999; Stull et al., 2007). During 2001, of 7382 nonambulatory fed and nonfed cattle arriving at 19 packing plants in Canada, 90% were dairy cattle (Doonan et al., 2003). Furthermore, this study reported that less than 1% of the nonambulatory cases developed during the transit process. Nearly all developed the nonambulatory condition on the farm of origin. There are a few medical reasons why the downer cow condition is more common in dairy cattle, but there is no justification for the transportation of animals with a high probability of becoming recumbent. Dairymen must be vigilant in their efforts to avoid transporting animals unfit for travel.

The term "downer" is generally reserved for an animal that is nonambulatory for a period of more than 24 h. Occurrence is highest in dairy cattle and is often traced to metabolic disorders, injuries, and infectious or toxic disease conditions. Periparturient hypocalcemia (milk fever) and complications associated with calving are the most common predisposing causes of the downer cow condition. In fact, one study identified the three major causes of downer cow problems in dairy cattle as hypocalcemia 19%, calving-related injuries 22%, and injuries from slipping and falling 15% (USAHA, 2006). By comparison, the primary cause of the downer cow syndrome in beef cattle is calving paralysis (Cox, 1981).

Estimates are that about 5% of dairy cattle in the United States are affected with hypocalcemia annually. The majority of cases (75%) occur within 24 h of calving, 12% of cases within 24–48 h of calving, and only about 6% of cases at calving. However, when hypocalcemia occurs prior to or in association with calving, it can be an important contributor to dystocia and associated complications.

Calving paralysis is a common cause of recumbency in cattle. It is usually the consequence of attempts to deliver a large calf relative to the size (i.e., size of the pelvis) of the cow. Paralysis results from damage to branches of the ischiadic (sciatic) and obturator nerves which are vulnerable to damage at calving by virtue of their position within the birth canal (Greenough, 1997). Evidence of damage to these nerves is frequently characterized by a knuckling of the rear foot in the early postcalving period.

Traumatic injuries may be the primary cause of recumbency, or they may occur as a secondary consequence of a cow that is down and struggling to rise. Examples of such lesions would include sacroiliac (hip) luxation, coxofemoral luxation (unilateral or bilateral), pelvic or other fractures, and rupture of the gastrocnemius tendon. These injuries also occur as a consequence of slips and falls. Injuries of the upper leg and pelvis increased significantly in cows during the summer months in a southeastern dairy as a result of wet concrete flooring conditions (Shearer et al., 2006).

Prognosis for Down Cows

Cows recumbent for prolonged periods are also subject to peripheral nerve injury and muscle damage that can increase the odds of a permanent nonambulatory state. Because of its sheer size and weight, a nonambulatory cow develops tremendous pressure on tissues of the down leg leading to decreased blood flow, hypoxia, and pressure necrosis of muscle and peripheral nervous system tissues. Because of its anatomic location, injury to distal branches of the sciatic nerve is particularly common in recumbent cattle. Ischemic damage to heavy muscles of the rear legs result in varying degrees of paresis that complicate the possibilities of recovery in affected animals. The condition synonymous with this in humans is "compartment syndrome" (Greenough, 1997).

One of the biggest challenges is determining—*how long should an animal be given to recover?* At least one study suggests the threshold for induction of permanent recumbency (down and unable to rise) in dairy cattle may be as short as 6 h. Of 84 periparturient cows down with hypocalcemia, 83 (98.8%) recovered when treatment was instituted within 6 h after they became recumbent (Fenwick et al., 1986). Similarly, a survey of

dairy producers indicated that nonambulatory cattle that recovered and remained in the herd were down for less than 6 h (USAHA, 2006). While good footing, attitude of the cow, and body condition are fundamental to recovery of nonambulatory animals, research from a U.K. study suggests that good nursing care may be the most important determinant in the favorable outcome of nonambulatory cattle (Chamberlain & Cripps, 1986).

From a clinical perspective, evidence of improvement is best indicated by the cow's attitude. When a cow makes frequent attempts to stand and continues to eat and drink, the likelihood of recovery is greater. Refusal to eat or drink, a preference to lie on one side (rather than roll from side to side), and resistance toward a caretaker's efforts to encourage standing or lying in normal resting positions suggest a poor prognosis for recovery. For animals experiencing injury, the convalescence period may be more prolonged.

Whenever the cause for the downer cow syndrome is in doubt, a veterinarian should be consulted for advice. As previously mentioned, it is unacceptable to allow nature to take its course in an animal that is suffering. It is important that when euthanasia is indicated in unresponsive downer animals, it be conducted in a timely manner. For this reason, these authors recommend that farm personnel be trained to conduct euthanasia for those circumstances that are likely to occur where a veterinarian may not be available.

Determination of the Most Appropriate Euthanasia Method

For on-farm euthanasia of cattle one may choose lethal injection. However, since barbiturates are controlled substances and must be administered by intravenous administration, a veterinarian must be available to perform the procedure. When veterinary supervision is *not* available, the most practical options for euthanasia of cattle are gunshot or captive bolt. Although proper use of both devices results in immediate unconsciousness, a secondary kill step is advised to ensure death, particularly when using captive bolt. Secondary kill steps include exsanguination, pithing, or possibly, the intravenous injection of 120 mL of a saturated solution of potassium chloride (KCl). Note: *An intravenous injection of KCl should never be done in conscious animals.* These are discussed in greater detail later in this chapter.

Firearms and Selection of the Appropriate Bullet, Shotshell, or Slug

Gunshot causes death by mass destruction of brain tissue. The degree of brain damage inflicted by the bullet is dependent upon the firearm, nature of the bullet (or shotshell as for a shotgun), and accuracy. For euthanasia purposes, handguns are limited to close-range shooting (within 1–2 ft or 30–60 cm) of the intended target. Shotguns loaded with either birdshot or slugs are appropriate from a distance of 1–2 yd (1–2 m) and rifles from a longer distance if required. Although all shotguns are lethal at close range, the preferred gauges for this procedure in cattle are the 20, 16, or 12 gauge shotguns. Number 6 or larger birdshot or shotgun slugs are the best choices for euthanasia of cattle.

For handguns or rifles, a solid point bullet is preferred over hollow points or soft lead bullets. Solid point bullets are more likely to penetrate the skull and accomplish the objective of damage to brain tissue. Although many people own or have access to a .22 caliber rifle, these are not advised for euthanasia of mature cattle. The bullet size, velocity, and muzzle energy are simply insufficient to achieve consistent results (National Animal Health Emergency Management System Guidelines, U.S. Department of Agriculture, January 2004). *Firearms should never be held flush to the animal's head or body*. The pressure within the barrel when fired may cause the barrel of the gun to explode. Ideally, the firearm should be angled in such manner that the bullet will travel toward the foramen magnum of the skull and down the spine. Proper positioning of the firearm is necessary to achieve the desired results. When euthanasia is performed by gunshot, the firearm should be held within 12–24 in. or a few feet of the intended target depending upon the type of gun being used. Ricochet may be prevented if the barrel of the firearm is positioned perpendicular to the skull.

Captive Bolt

There are two basic types of captive bolt: penetrating and nonpenetrating. Both are intended to cause an immediate loss of consciousness. Styles include an in-line (cylindrical) and pistol grip (resembling a handgun) versions. Pneumatic captive bolt guns (air powered) are limited to use in slaughter plant environments. Models using gunpowder charges are more often used in farm environments.

The ability to kill versus stun (make unconscious) is dependent upon bolt length, caliber, and cartridge power. Generally speaking, captive bolt guns induce immediate loss of consciousness, but death is not assured with the use of this device alone. A secondary kill step such as exsanguination, pithing, or the intravenous injection of a concentrated solution of KCl is recommended to

ensure death (described in greater detail later in the section "Secondary Kill Steps").

Penetrating captive bolt devices are used for euthanasia of mature cattle in field situations. They consist of a steel bolt, with a flange and piston at one end, housed within a barrel. Upon firing, the rapid expansion of gas within the breech and barrel propels the piston forward and through the muzzle. A series of cushions are strategically located within the barrel to dissipate excess energy of the bolt. Depending upon model, the bolt may be retracted back into the gun either automatically or by manually pushing it back into the muzzle where it is designed to lock in place. Accurate placement, energy (i.e., bolt velocity), and depth of penetration of the bolt determine stunning effectiveness. Bolt velocity is dependent on maintenance, in particular, cleaning and storage of the cartridge charges.

Captive bolt guns should only be used by trained people. Even though the bolt protrudes only a short distance from the muzzle end, it should always be pointed toward the ground and away from the body or bystanders in case of accidental discharge. Protective gear for both ears and eyes are strongly recommended.

Unlike techniques described for gunshot, the animal must be restrained appropriately for accurate placement of the captive bolt. Once restrained, stunning should occur with little or no delay so that animal distress is minimized. Proper stunning requires that the muzzle of the captive bolt be held firmly against the animal's head. Secondary kill steps should be implemented as soon as the animal is rendered unconscious to avoid a possible return to sensibility. Thus, when conducting euthanasia by captive bolt, some preplanning and preparation improves the likelihood of a successful outcome.

The most common cause of misfires and ineffective kills is poor maintenance. Captive bolt guns must be cleaned and maintained in order to operate effectively. For guns that are not used regularly, periodic cleaning and oiling along with storage in a clean, dry environment assures proper functioning of the device. Same is true for storage of powder charges. Exposure to moisture or humidity can cause misfires.

Anatomical Landmarks in Cattle

In cattle, the point of entry of the projectile should be on the intersection of two lines each drawn from the top or rear corner of the eye to the base of the opposite horn. The firearm should be positioned so that the muzzle is perpendicular to the skull to avoid the possibility of ricochet. Ideally, the bullet should travel toward the foramen magnum or in the direction of the tail of the animal as shown in Figure 25.1. Proper positioning of the firearm or penetrating captive bolt is necessary to achieve the desired results.

Secondary Kill Steps

Captive bolt is intended to induce immediate unconsciousness by causing damage to the central nervous system, but death is not certain. Therefore, operators should be prepared to apply a secondary kill step that may consist of exsanguination, pithing, or possibly a rapid intravenous injection of KCl. The specific dose of KCl will vary according to size of the animal. These are described in the following.

Exsanguination

Exsanguination should be performed using a pointed, very sharp knife with a rigid blade at least 6 in. in length. The knife should be fully inserted through the skin just behind the point of the jaw and below the neck bones. From this position the knife is drawn forward severing the jugular vein, carotid artery, and windpipe. Properly performed, blood should flow freely with death occurring over a period of several minutes. Exsanguination should never be used as a sole method of euthanasia and the animal must be stunned prior to bleeding. This procedure can be very disturbing to observers due to the large volume of blood loss, which also raises biosecurity concerns.

Pithing

Pithing is a technique designed to cause death by increasing the destruction of brain and spinal cord tissue. It is performed by inserting a pithing rod or similar tool through the entry site produced in the skull by the penetrating captive bolt stunner. The operator manipulates the pithing tool to destroy both brain stem and spinal cord tissue which results in death. This procedure is sometimes used in advance of exsanguination procedures to reduce involuntary movement in stunned animals.

A pithing rod can be made from a variety of materials such as a discarded cattle insemination gun or other similar device. Disposable pithing rods are available for purchase in some countries. The rod itself must be somewhat rigid, yet flexible. It must be long enough to reach the brain and upper region of the spinal column through the hole in the skull produced by the projectile from a gun or penetrating captive bolt.

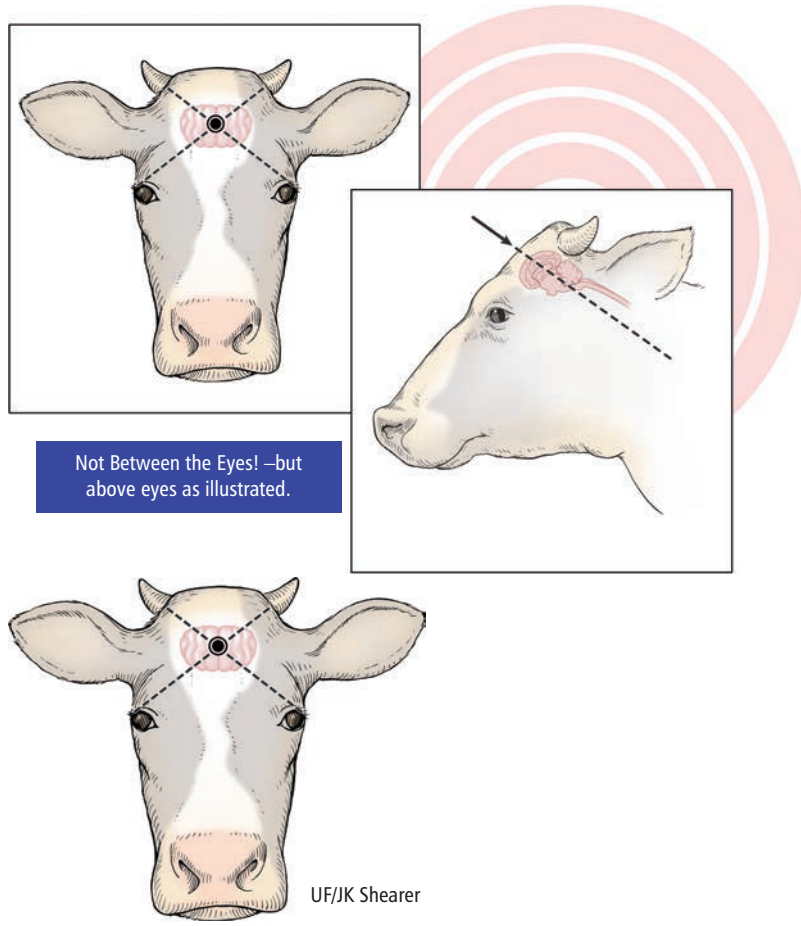

Figure 25.1. Anatomical site for gunshot or captive bolt.

Intravenous Injection of KCl

Another option for ensuring death once the animal has been rendered unconscious is through the rapid injection of a concentrated solution of KCl. KCl is a salt solution which when delivered by rapid intravenous injection induces cardiac arrest. Normally, the injection of 120 mL of a saturated solution of KCl is sufficient to cause death; however, the KCl solution should be given to effect (i.e., until death is assured). KCl is readily available as water softener salt. To prepare a saturated solution of KCl, one may simply dissolve the salt in water until the solution becomes saturated. Heating and frequent stirring helps put the salt into solution. It is advised that when conducting euthanasia that may require KCl, the operator prepares at least two 60 mL syringes (equipped with a 14- or 16-gauge needles) filled with the saturated KCl solution prior to rendering the animal unconscious. In this way, the injection may be made as soon as possible once the animal is unconscious. Any available vein may be used; however, it is important to position oneself out of the reach of feet and legs which may cause injury during periods of involuntary movement. In most cases, it is safest to kneel down near the animal's dorsum and close to the animal's head where one may reach over the neck to administer the intravenous injection into the jugular vein. Once the needle is in the vein, the injection should be delivered by rapid intravenous injection. Death will usually occur within a couple of minutes. *Please note that KCl should never be used in conscious animals. KCl causes death by inducing cardiac arrest.*

Euthanasia for Calves

Neonatal calves present special problems regarding euthanasia. As with adult cattle, the choices for method of euthanasia are barbiturate injection, gunshot, and captive bolt. Blunt trauma by physical blow to the head is not acceptable in calves (AVMA Guidelines on Euthanasia, 2007) because the calf skull is too hard to achieve immediate destruction of brain tissue and unconsciousness. Nonpenetrating captive bolt can be

used to achieve immediate unconsciousness because the amount of force is sufficient and can be controlled (see next section).

Because the calf skull and cranium are smaller, physical methods such as gunshot and captive bolt require accurate placement and direction to assure penetration of the brain. The captive bolt device must be placed similar to that described earlier for adult cattle. The direction toward the foramen magnum is critical in calves because the head is often rotated during restraint, and a direction perpendicular to the skull may be too rostral, resulting in penetration of the frontal sinus.

Standard length captive bolt may not be sufficient to cause death in neonatal calves and should be followed by a secondary kill step such as exsanguination, pithing, or KCl IV.

Euthanasia of Dairy Calves Using Controlled Blunt Force Trauma

Controlled blunt force trauma induces euthanasia by physical disruption of the brain. Acceptable tools for controlled blunt force trauma include cartridge and pneumatic nonpenetrating captive bolt guns. It should be noted that controlled blunt force trauma differs from manual blunt force trauma. "Controlled" blunt force trauma devices deliver a uniform amount of force each time they are fired. These are not recommended for mature animals, but some research suggests they may be useful for euthanasia of calves when combined with a secondary kill step as described previously.

It is important to be sure that the animal is properly stunned before applying secondary kill procedures. Signs indicative of proper stunning would include the following responses: (1) immediate collapse of the animal with no attempt to stand up when stunned, (2) initially muscles become rigid following the shot with involuntary movement of limbs occurring soon thereafter, (3) normal rhythmic breathing is interrupted or stops, and (4) the eyes remain open and are not rotated. Vocalization, attempts to stand, or evidence of righting reflexes are indicative of an improper stun and should not be followed by use of secondary kill steps. In this unfortunate event, the operator should immediately prepare to restun the animal.

Confirmation of Death in Euthanized Animals

Regardless of the method of euthanasia used, death must be confirmed before disposal of the animal. The following should be used to evaluate consciousness or confirm death.

- Lack of a heartbeat
- Lack of respiration
- Lack of a palpebral/corneal reflex
- Lack of movement over a period of several hours
- Presence of rigor mortis

The presence of a heartbeat can best be determined with a stethoscope placed under the left elbow. However, it should be noted that a pulse may not be palpable under such circumstances and should not be used to confirm death. Movement of the chest indicates respiration but respiration rates may be very erratic and time between breaths prolonged in unconscious animals. Therefore, one must be cautious in the interpretation of respiration for confirmation of death.

Palpebral reflexes may be checked by running a finger along the eyelashes to detect reflexive movement of the lids. One may also test for evidence of a corneal reflex by touching the surface of the eyeball. A conscious animal will blink when the eyeball is touched.

An alternative is to observe the animal over a period of several hours. Lack of movement, absence of a heartbeat, respiration, or corneal reflex over an extended period of time provides further confirmation of death. Finally, the presence of rigor mortis (i.e., stiffening of a dead body) and bloat are sure signs of death, but generally do not occur until after a period of several hours.

Additional Considerations for Conducting Euthanasia Procedures

Choices of one method of euthanasia over another should include concerns for human safety, animal welfare, ability to restrain the animal for proper application of the procedure, skill of the person performing the procedure, cost, rendering and carcass disposal considerations, emotional distress to the person performing the task as well as bystanders, and possibly, potential need for brain tissue (for diagnostic purposes) in the event the animal is suspected of having rabies. We discuss a few of these in the following.

It is important that handlers do all they can to minimize pain, fear, distress, and anxiety for the animal to be euthanized. If animals are accustomed to human contact, the presence of a familiar person may be reassuring and reduce anxiety. On the other hand, for wildlife and animals unaccustomed to human contact, gunshot may be the method of choice since it can be delivered with the least amount of human contact necessary. If the animal to be euthanized is ambulatory and able to be moved without causing distress, discomfort, or pain, it may be moved to an area where the carcass may be more easily reached by removal equipment. Dragging of nonambulatory animals is unacceptable. In cases where

movement may increase distress or animal suffering, the animal should be euthanized first, and moved following confirmation of death.

Animals should not be carried or swung in a way that would cause pain or distress. They should be restrained as gently as possible and the welfare and safety of other animals in the immediate environment must always be considered (i.e., chance of missed gunshot hitting other animals, or startling other animals). Euthanasia of an animal in the presence of healthy animal peers may be very distressful. If possible, remove healthy animals to another location when euthanasia is necessary.

Involuntary movement and muscular spasms are normal responses of animals during the euthanasia procedure. This can be hazardous for the handler as well as any assistants. It is also important to recognize that these involuntary movements are distressful for people inexperienced with these procedures. A forewarning to bystanders ahead of time helps reduce the amount of explanation that may be necessary afterward.

Euthanasia of fractious animals (such as an aggressive bull or cow) may require capture in a chute where the animal can be tranquilized and released to a pen that is accessible by removal equipment. Once the tranquilizer has taken effect and the animal is immobilized, it may be euthanized by captive bolt or gunshot depending upon which is safest for handlers and assistants.

In all cases the method chosen must be appropriate for the animal and situation for which it is to be used. Captive bolt and/or gunshot are appropriate methods for commercial livestock operation applications, but they may not be appropriate for euthanasia of a child's horse.

Some methods of euthanasia are more costly and require more maintenance than others. Captive bolt guns have a high initial cost, but are inexpensive to use. The biggest drawback is maintenance. Captive bolt devices must be cleaned regularly, and the ammunition charges must be stored so that the powder remains dry. Failure in either case will result in misfire which is the primary cause of ineffective stunning with these devices. Cost is minimal with gunshot and captive bolt, but where human emotion is involved, other methods will likely be more appealing.

Anesthetic overdose has a relatively high cost since a veterinarian must perform the procedure, and carcass disposal may be complicated by drug residue. The number of animals euthanized within the operation is also a consideration. If only an occasional animal is euthanized, cost is not a significant factor compared with a larger operation that may be required to euthanize animals more frequently or may be in the position of conducting mass euthanasia of livestock.

Each method of euthanasia requires a certain level of skill and training. This is an extremely important consideration as the skill and efficiency of the person performing the task is vital for the proficiency of the task. Improper use of the tool will not only jeopardize the safety of the handler, but also the welfare of the animal. Most cases of failed euthanasia are a result of human error. No matter what the skill level requires, euthanasia procedures should be routinely assessed to ensure the welfare of the animals and safety of the handler.

Personnel Training

Large farms and ranches are advised to develop personnel training programs for proper instruction of humane euthanasia techniques. As indicated in the previous discussion, there is a certain amount of knowledge and skill required to conduct these procedures successfully. Experience has shown that many people (even those experienced in handling livestock) are not aware of the anatomical landmarks for proper execution of these techniques. Furthermore, people need to be aware of the danger for the operator as well as bystanders with gunshot as well as captive bolt. On large farms or ranches, most, if not all, persons should be familiar with these procedures and several should be specifically trained to perform these tasks. However, only those who can demonstrate a working knowledge and proficiency with the techniques should be permitted to perform euthanasia procedures. When these methods are not properly performed, animals may become injured, have varying degrees of consciousness, and experience needless pain and distress.

Experienced persons may assist in the training of inexperienced persons and may utilize the carcasses of deceased animals to demonstrate anatomical landmarks and application of the various techniques. Carcasses should be used for practice by trainees until they become competent with the procedures. People must also be aware of how to confirm death. In some cases this may require specific training with, and observation of, live animals.

The mode of disposal of the carcass must also be considered in determining the most appropriate method of euthanasia. If it is likely that a carcass may be consumed by scavengers (buzzards, coyotes, etc.), it cannot be euthanized with drugs. Animals that are going to require screening or testing after death (such as for rabies diagnosis) must be euthanized in a way that will not damage or destroy the brain. Different regions have different laws regulating the disposal of dead livestock, so readers are advised to familiarize themselves with local ordinances and laws.

A final consideration is for the person who must perform the task of humane euthanasia. It is important to recognize that this is not a procedure that all persons are mentally or emotionally able to perform. This is particularly true if a person is in a position where they must perform these procedures repetitively. Observation has shown that constant exposure to, or participation in, euthanasia procedures may result in psychological damage leading to work-related dissatisfaction and a tendency toward careless or callous handling of animals. One strategy for managing this problem includes providing adequate training so that euthanasia procedures may be competently applied. Another may be to change work duties as needed to provide relief when it becomes apparent that such duties are causing emotional distress. Euthanasia, regardless of the circumstances, impacts a person's emotional state (AVMA Guidelines, 2007). Sensitivity to this issue should not be overlooked by both veterinarian and producer.

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26

Managing Herd Health in Organic Herds

Juan S. Velez

Abstract

The organic dairy industry in the United States is projected to grow as more consumers will choose to purchase organic milk products. Therefore, veterinarians engaged in dairy practice have an opportunity to work closely with organic dairy producers in establishing management practices within an organic farm setting. This chapter provides guidance and illustrates organic herd health protocols and practices that have proven effective in organic dairy farms.

Introduction

The organic dairy industry in the United States has been growing at a rate of approximately 20% per year over the last 10 years (Organic Trade Association, www.ota.com/index.html). It is projected that it will continue to grow at a similar rate for the next 5 years. As shown in Figure 26.1, this translates into a growth of the nation's organic dairy herd from 72,000 cows in 2004 to 173,000 in 2008 (Drifmier, 2008, personal communication). This growth has come from the transitioning of small farms from conventional to organic as well as from the start of new, larger organic farms. Although organic cows comprise only a small percent of the total dairy herd population in the United States, the organic dairy herd continues to grow. Consequently, opportunities for veterinarians to provide service to organic dairy farmers will increase. In addition, it is imperative that veterinarians take charge and become intimately involved in the design and implementation of management programs for dairy cattle within the constraint of an organic farm setting. To accomplish this, the practicing veterinarian must be familiar with the organic regulations of the respective country.

The objective of this chapter is to provide guidance and to illustrate organic herd health protocols and practices that have been effective in organic dairy herds (see Fig. 26.1).

Importance of Protocols

The importance of documentation and retention of information as required by the organic certification agency cannot be overemphasized. In some countries it is stated that all records be maintained for a period of 5 years. Along with this requirement, in order for the organic inspector to perform an audit, farms must have a record or system that can track individual animal information.

Management of herd health in dairies requires development and implementation of systems and herd health protocols so that animal caretakers can consistently execute the practices that will maintain and improve the well-being of the animals. In organic herds, written herd health protocols become even more important for the following reasons:

Dairy Production Medicine, First Edition. Edited by Carlos A. Risco, Pedro Melendez Retamal.

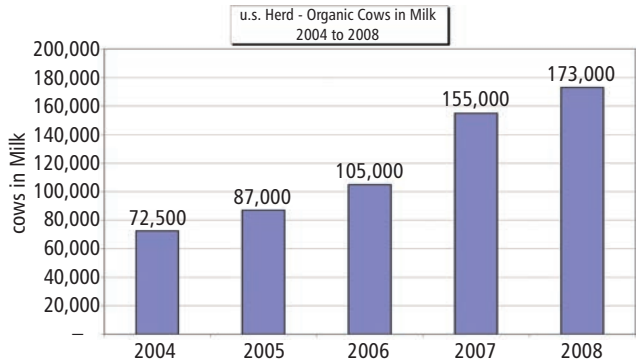

Figure 26.1. Growth of the United States organic dairy herds from 2004 to 2008 (Drifmier, 2008, personal communication).

1. They are essential for training and continuing education of owners, managers, and personnel.
2. Documentation and retention of information is required by the certification process.
3. They are necessary for the evaluation of efficacy of alternative and supportive treatments, hence the need for consistency.
4. The documentation can protect against the risk of potential use of prohibited substances and potential risk of failing to obey by the withdrawal periods for the approved substances established by the National Organic Program (NOP).

The foundation of organic herd health protocols is prevention. Prevention methods do not differ significantly between organic and conventional systems. However, the playing field is different when antibiotics, hormones, and other synthetic medicines are eliminated from the medicine toolbox in the organic system. Therefore, prevention programs become much more important for the organic herd. Every small detail must be taken seriously in order to improve cow comfort and welfare.

Even though prevention practices in principle do not differ significantly between organic herds and conventional herds, it is the author's experience that the following are important preventive measurements that have proven to be very effective in organic herds.

First and foremost, the training and motivation of the individuals who will be implementing preventive medicine protocols is the most important aspect of the entire program. Maintaining the motivation and the skills of the animal caretaker to prevent drifting from the original document is an important function in which, in the author's opinion, the veterinarian must be deeply involved.

Table 26.1. Mastitis control and milk quality

Practice	Rationale
Strict adherence to milking procedures as recommended by the National Mastitis Council (NMC, 1961)	There is no effective treatment available under organic management. Shortcuts to the recommended routine will result in higher probability of mastitis.
Use of milking equipment with a back flush system	Antibiotic dry cow therapy is prohibited, making it difficult to eliminate contagious bacteria. Back flush systems help prevent the spreading of contagious bacteria.
Proper maintenance and use of milking equipment as recommended by the National Mastitis Council (NMC, 1961)	Adherence to a strict schedule for full parlor maintenance and evaluation is paramount in prevention of new infections.
Intermittent milking of cows going dry (milk once a day for 5 days)	Sudden drying without the use of dry cow therapy increases the probability of new infections. Intermittent milking prevents udders from leaking after drying and decreases the risk of mastitis.
Culturing and culling of chronically infected cows	Elimination of cows positive to contagious bacteria reduces the risk of spreading the contagious organisms.
Use of core antigen vaccine against infections with coliform bacteria	This practice has proven to reduce incidence of coliform mastitis.
Good grazing practices avoid muddy areas.	Grazing is a must in organic systems. Muddy areas in pastures will increase the probability of mastitis.

Practices such as nutrition, cow comfort, and preventive and production medicine in dairy cows have been discussed elsewhere in this book. This chapter focuses on preventive practices that could be superfluous in conventional dairies. However, it is the author's experience that the following practices are very important in the management of herd health in organic dairies.

Tables 26.1–26.4 show suggestions for control of mastitis and lameness and for reproductive management and calf rearing, respectively.

Table 26.2. Lameness control

Practice	Rationale
In-house hoof care specialist	Preventive trimming, as well as early and correct diagnosis of lameness, allows for effective treatments under organic management.
Use of rubber mats for flooring	Improve hoof sole health and cow comfort.
Proper use of foot baths	Copper sulfate for foot baths is allowed, which prevents infectious foot disorders.
Good grazing practices to avoid muddy areas	Grazing is a must in organic systems. Muddy areas in pastures will increase the probability of infectious claw disorders.
Clean alleys and holding areas	Prevention of spread of digital and interdigital dermatitis

Table 26.3. Reproductive management

Practice	Rationale
Breed Holstein heifers to a small breed bull (i.e., Jersey)	In the author's experience, the incidence of dystocia is significantly reduced. Lowering the incidence of dystocia reduces postpartum metritis in primiparous cows.
Infusion of 500 mg of iodine per cow every other day for 3 days in cows at risk of toxic postpartum metritis (those with dystocia, retained placenta, stillbirth, twins)	Without the use of antibiotics for the treatment of metritis, the use of iodine as an early intervention for at risk cows is permitted in organic dairy farms. In the author's experience, this practice has been efficacious when compared with nontreated cows.
When natural service is used, must follow guidelines for bull management as described by Risco et al. (1998)	Poor bull management results in reproductive inefficiencies in both conventional and organic systems.
When artificial insemination is used, visual estrus detection is of critical importance. Constant training of personnel and application of estrus detection aids is a must.	Without the use of hormones to synchronize ovulation or shorten the estrous cycle, detection of estrus becomes the single most important factor for a successful artificial insemination program in organic dairies.

Table 26.4. Calf rearing

Practice	Rationale
Comprehensive vaccination program	Without the use of antibiotics, vaccines become the first line of defense.
Testing every calf for persistently infected (PI) bovine viral diarrhea (BVD) calves and culling those that are positive	One positive PI calf is devastating in an organic calf-rearing system because there are no antibiotics in the milk replacer or feed grain to help control infectious diseases.
Weekly monitoring of serum total proteins to determine failure of passive transfer prevalence in all calves (Donovan et al., 1986)	Immediate reaction and feedback to the colostrum management program is imperative in an organic system. Without the use of antibiotics, a late reaction to a deficient program of passive transfer could be devastating.

Individual Cow Treatments in Organic Herd Health

It is critical that the practitioner be knowledgeable of the approved and disapproved substances for therapy. For European standards, refer to the International Federation of Organic Agricultural Movement (IFOAM, www.ifoam.org/about_ifoam/standards/index.html). For United States standards, refer to the National Organic Program (NOP, http://www.ams.usda.gov/AMSv1.0/NOP). Another excellent source of information is the Organic Material Review Institute (OMRI, http://www.omri.org/).

As a general rule, under the NOP, any product that is natural is allowed, unless it is listed as prohibited, and everything that is synthetic is prohibited unless listed as allowed. The basics of organic cow treatment are supportive therapy. Restoration of hydration is of critical importance with any sick animal, and the organic cow is no different. Fortunately, electrolytes are allowed in organic production. Fever reducers are also allowed and they are critical to help the cow maintain her appetite during ill-health. Several textbooks are available that discuss the use of alternative medicine therapies in organic cows. The author has found the book *Treating Dairy Cows Naturally* to be a very good source of information for individual cow treatments (Karreman, 2008). It is the author's opinion that there are opportunities for research in the area of the use of natural products for the treatment of dairy cows. Many

recommendations in this area lack scientific scrutiny to support their use.

Conclusions

Organic dairying is growing around the world. The practicing veterinarian has a great opportunity to become involved in developing these organic systems and protocols to make sure that organic production operations manage their herds for maximum animal well-being and profit. Knowledge of organic regulations is imperative to obtain such goal. Prevention is the most important aspect of organic herd health. There are great opportunities for research in the area of alternative natural treatments for organic cows.

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