Chinese Academy of Sciences

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Science & Technology on Public Health in China: A Roadmap to 2050

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Foreword to the Roadmaps 2050*

China's modernization is viewed as a transformative revolution in the human history of modernization. As such, the Chinese Academy of Sciences (CAS) decided to give higher priority to the research on the science and technology (S&T) roadmap for priority areas in China's modernization process. What is the purpose? And why is it? Is it a must? I think those are substantial and significant questions to start things forward.

Significance of the Research on China's S&T Roadmap to 2050

We are aware that the National Mid- and Long-term S&T Plan to 2020 has already been formed after two years' hard work by a panel of over 2000 experts and scholars brought together from all over China, chaired by Premier Wen Jiabao. This clearly shows that China has already had its S&T blueprint to 2020. Then, why did CAS conduct this research on China's S&T roadmap to 2050?

In the summer of 2007 when CAS was working out its future strategic priorities for S&T development, it realized that some issues, such as energy, must be addressed with a long-term view. As a matter of fact, some strategic researches have been conducted, over the last 15 years, on energy, but mainly on how to best use of coal, how to best exploit both domestic and international oil and gas resources, and how to develop nuclear energy in a discreet way. Renewable energy was, of course, included but only as a supplementary energy. It was not yet thought as a supporting leg for future energy development. However, greenhouse gas emissions are becoming a major world concern over

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* It is adapted from a speech by President Yongxiang Lu at the first High level Workshop on China's S&T Roadmap for Priority Areas to 2050, organized by the Chinese Academy of Sciences, in October, 2007.

the years, and how to address the global climate change has been on the agenda. In fact, what is really behind is the concern for energy structure, which makes us realize that fossil energy must be used cleanly and efficiently in order to reduce its impact on the environment. However, fossil energy is, pessimistically speaking, expected to be used up within about 100 years, or optimistically speaking, within about 200 years. Oil and gas resources may be among the first to be exhausted, and then coal resources follow. When this happens, human beings will have to refer to renewable energy as its major energy, while nuclear energy as a supplementary one. Under this situation, governments of the world are taking preparatory efforts in this regard, with Europe taking the lead and the USA shifting to take a more positive attitude, as evidenced in that: while fossil energy has been taken the best use of, renewable energy has been greatly developed, and the R&D of advanced nuclear energy has been reinforced with the objective of being eventually transformed into renewable energy. The process may last 50 to 100 years or so. Hence, many S&T problems may come around. In the field of basic research, for example, research will be conducted by physicists, chemists and biologists on the new generation of photovoltaic cell, dye-sensitized solar cells (DSC), high-efficient photochemical catalysis and storage, and efficient photosynthetic species, or high-efficient photosynthetic species produced by gene engineering which are free from land and water demands compared with food and oil crops, and can be grown on hillside, saline lands and semi-arid places, producing the energy that fits humanity. In the meantime, although the existing energy system is comparatively stable, future energy structure is likely to change into an unstable system. Presumably, dispersive energy system as well as higher-efficient direct current transmission and storage technology will be developed, so will be the safe and reliable control of network, and the capture, storage, transfer and use of CO_2, all of which involve S&T problems in almost all scientific disciplines. Therefore, it is natural that energy problems may bring out both basic and applied research, and may eventually lead to comprehensive structural changes. And this may last for 50 to 100 years or so. Taking the nuclear energy as an example, it usually takes about 20 years or more from its initial plan to key technology breakthroughs, so does the subsequent massive application and commercialization. If we lose the opportunity to make foresighted arrangements, we will be lagging far behind in the future. France has already worked out the roadmap to 2040 and 2050 respectively for the development of the 3rd and 4th generation of nuclear fission reactors, while China has not yet taken any serious actions. Under this circumstance, it is now time for CAS to take the issue seriously, for the sake of national interests, and to start conducting a foresighted research in this regard.

This strategic research covers over some dozens of areas with a long-term view. Taking agriculture as an example, our concern used to be limited only to the increased production of high-quality food grains and agricultural by-products. However, in the future, the main concern will definitely be given to the water-saving and ecological agriculture. As China is vast in territory, diversified technologies in this regard are the appropriate solutions. Animal husbandry has been used by developed countries, such as Japan and Denmark, to make bioreactor and pesticide as well. Plants have been used by Japan to make bioreactors which are safer and cost-effective than that made from animals. Potato, strawberry, tomato and the like have been bred in germ-free greenhouses, and value-added products have been made through gene transplantation technology. Agriculture in China must not only address the food demands from its one billions-plus population, but also take into consideration of the value-added agriculture by-products and the high-tech development of agriculture as well. Agriculture in the future is expected to bring out some energies and fuels needed by both industry and man's livelihood as well. Some developed countries have taken an earlier start to conduct foresighted research in this regard, while we have not yet taken su ficient consideration.

Population is another problem. It will be most likely that China's population will not drop to about 1 billion until the end of this century, given that the past mistakes of China's population policy be rectified. But the subsequent problem of ageing could only be sorted out until the next century. The current population and health policies face many challenges, such as, how to ensure that the 1.3 to 1.5 billion people enjoy fair and basic public healthcare; the necessity to develop advanced and public healthcare and treatment technologies; and the change of research priority to chronic diseases from infectious diseases, as developed countries have already started research in this regard under the increasing social and environmental change. There are many such research problems yet to be sorted out by starting from the basic research, and subsequent policies within the next 50 years are in need to be worked out.

Space and oceans provide humanity with important resources for future development. In terms of space research, the well-known Manned Spacecraft Program and China's Lunar Exploration Program will last for 20 or 25 years. But what will be the whole plan for China's space technology? What is the objective? Will it just follow the suit of developed countries? It is worth doing serious study in this regard. The present spacecraft is mainly sent into space with chemical fuel propellant rocket. Will this traditional propellant still be used in future deep space exploration? Or other new technologies such as electrical propellant, nuclear energy propellant, and solar sail technologies be developed? We haven't yet done any strategic research over these issues, not even worked out any plans. The ocean is abundant in mineral resources, oil and gas, natural gas hydrate, biological resources, energy and photo-free biological evolution, which may arise our scientific interests. At present, many countries have worked out new strategic marine plans. Russia, Canada, the USA, Sweden and Norway have centered their contention upon the North Pole, an area of strategic signi icance. For this, however, we have only limited plans.

The national and public security develops with time, and covers both conventional and non-conventional security. Conventional security threats only refer to foreign invasion and warfare, while, the present security threat may come out from any of the natural, man-made, external, interior, ecological, environmental, and the emerging networking (including both real and virtual) factors. he con licts out of these must be analyzed from the perspective of human civilization, and be sorted out in a scienti ic manner. E forts must be made to root out the cause of the threats, while human life must be treasured at any time.

In general, it is necessary to conduct this strategic research in view of the future development of China and mankind as well. The past 250 years' industrialization has resulted in the modernization and better-off life of less than 1 billion people, predominantly in Europe, North America, Japan and Singapore. The next 50 years' modernization drive will definitely lead to a better-off life for 2–3 billion people, including over 1 billion Chinese, doubling or tripling the economic increase over that of the past 250 years, which will, on the one hand, bring vigor and vitality to the world, and, on the other hand, inevitably challenge the limited resources and eco-environment on the earth. New development mode must be shaped so that everyone on the earth will be able to enjoy fairly the achievements of modern civilization. Achieving this requires us, in the process of China's modernization, to have a foresighted overview on the future development of world science and human civilization, and on how science and technology could serve the modernization drive. S&T roadmap for priority areas to 2050 must be worked out, and solutions to core science problems and key technology problems must be straightened out, which will eventually provide consultations for the nation's S&T decision-making.

Possibility of Working out China's S&T Roadmap to 2050

Some people held the view that science is hard to be predicted as it happens unexpectedly and mainly comes out of scientists' innovative thinking, while, technology might be predicted but at the maximum of 15 years. In my view, however, S&T foresight in some areas seems feasible. For instance, with the exhaustion of fossil energy, some smart people may think of transforming solar energy into energy-intensive biomass through improved high-e ficient solar thin-film materials and devices, or even developing new substitute. As is driven by huge demands, many investments will go to this emerging area. It is, therefore, able to predict that, in the next 50 years, some breakthroughs will undoubtedly be made in the areas of renewable energy and nuclear energy as well. In terms of solar energy, for example, the improvement of photoelectric conversion e ficiency and photothermal conversion e ficiency will be the focus. Of course, the concrete technological solutions may be varied, for example, by changing the morphology of the surface of solar cells and through the reflection, the entire spectrum can be absorbed more e ficiently; by developing multi-layer functional thin-films for transmission and absorption; or by introducing of nanotechnology and quantum control technology, etc. Quantum control research used to limit mainly to the solution to information functional materials. This is surely too narrow. In the future, this research is expected to be extended to the energy issue or energy-based basic research in cutting-edge areas.

In terms of computing science, we must be con ident to forecast its future development instead of simply following suit as we used to. his is a possibility rather than wild fancies. Information scientists, physicists and biologists could be engaged in the forward-looking research. In 2007, the Nobel Physics Prize was awarded to the discovery of colossal magneto-resistance, which was, however, made some 20 years ago. Today, this technology has already been applied to hard disk store. Our conclusion made, at this stage, is that: it is possible to make long-term and unconventional S&T predictions, and so is it to work out China's S&T roadmap in view of long-term strategies, for example, by 2020 as the first step, by 2030 or 2035 as the second step, and by 2050 as the maximum.

This possibility may also apply to other areas of research. he point is to emancipate the mind and respect objective laws rather than indulging in wild fancies. We attribute our success today to the guidelines of emancipating the mind and seeking the truth from the facts set by the Third Plenary Session of the 11th Central Committee of the Communist Party of China in 1979. We must break the conventional barriers and find a way of development fitting into China's reality. The history of science tells us that discoveries and breakthroughs could only be made when you open up your mind, break the conventional barriers, and make foresighted plans. Top-down guidance on research with increased financial support and involvement of a wider range of talented scientists is not in conflict with demand-driven research and free discovery of science as well.

Necessity of CAS Research on China's S&T Roadmap to 2050

Why does CAS launch this research? As is known, CAS is the nation's highest academic institution in natural sciences. It targets at making basic, forward-looking and strategic research and playing a leading role in China's science. As such, how can it achieve this if without a foresighted view on science and technology? From the perspective of CAS, it is obligatory to think, with a global view, about what to do after the 3rd Phase of the Knowledge Innovation Program (KIP). Shall we follow the way as it used to? Or shall we, with a view of national interests, present our in-depth insights into different research disciplines, and make efforts to reform the organizational structure and system, so that the innovation capability of CAS and the nation's science and technology mission will be raised to a new height? Clearly, the latter is more positive. World science and technology develops at a lightening speed. As global economy grows, we are aware that we will be lagging far behind if without making progress, and will lose the opportunity if without making foresighted plans. S&T innovation requires us to make joint efforts, break the conventional barriers and emancipate the mind. This is also what we need for further development.

The roadmap must be targeted at the national level so that the strategic research reports will form an important part of the national long-term program. CAS may not be able to fulfill all the objectives in the reports. However, it can select what is able to do and make foresighted plans, which will eventually help shape the post-2010 research priorities of CAS and the guidelines for its future reform.

Once the long-term roadmap and its objectives are identified, system mechanism, human resources, funding and allocation should be ensured for full implementation. We will make further studies to figure out: What will happen to world innovation system within the next 30 to 50 years? Will universities, research institutions and enterprises still be included in the system? Will research institutes become grid structure? When the cutting-edge research combines basic science and high-tech and the transformative research integrates the cutting-edge research with industrialization, will that be the research trend in some disciplines? What will be the changes for personnel structure, motivation mechanism and upgrading mechanism within the innovation system? Will there be any changes for the input and structure of innovation resources? If we could have a clear mind of all the questions, make foresighted plans and then dare to try out in relevant CAS institutes, we will be able to pave a way for a more competitive and smooth development.

Social changes are without limit, so are the development of science and technology, and innovation system and management as well. CAS must keep moving ahead to make foresighted plans not only for science and technology, but also for its organizational structure, human resources, management modes, and resource structures. By doing so, CAS will keep standing at the forefront of science and playing a leading role in the national innovation system, and even, frankly speaking, taking the lead in some research disciplines in the world. his is, in fact, our purpose of conducting the strategic research on China's S&T roadmap.

Prof. Dr.-Ing. Yongxiang Lu
President of the Chinese Academy of Sciences

Preface to the Roadmaps 2050

CAS is the nation's think tank for science. Its major responsibility is to provide S&T consultations for the nation's decision-makings and to take the lead in the nation's S&T development.

In July, 2007, President Yongxiang Lu made the following remarks: "In order to carry out the Scientific Outlook of Development through innovation, further strategic research should be done to lay out a S&T roadmap for the next 20–30 years and key S&T innovation disciplines. And relevant workshops should be organized with the participation of scientists both within CAS and outside to further discuss the research priorities and objectives. We should no longer confine ourselves to the free discovery of science, the quantity and quality of scientific papers, nor should we satisfy ourselves simply with the Principal Investigators system of research. Research should be conducted to address the needs of both the nation and society, in particular, the continued growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature. "

According to the Executive Management Committee of CAS in July, 2007, CAS strategic research on S&T roadmap for future development should be conducted to orchestrate the needs of both the nation and society, and target at the three objectives: the growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature.

In August, 2007, President Yongxiang Lu further put it: "Strategic research requires a forward-looking view over the world, China, and science & technology in 2050. Firstly, in terms of the world in 2050, we should be able to study the perspectives of economy, society, national security, eco-environment, and science & technology, specifically in such scientific disciplines as energy, resources, population, health, information, security, eco-environment, space and oceans. And we should be aware of where the opportunities and challenges lie. Secondly, in terms of China's economy and society in 2050, we should take into consideration of factors like: objectives, methods, and scientific supports needed for economic structure, social development, energy structure, population and health, eco-environment, national security and innovation capability. Thirdly, in terms of the guidance of Scientific Outlook of Development on science and technology, it emphasizes the people's interests and development, science and technology, science and economy, science and society, science and eco-environment, science and culture, innovation and collaborative development. Fourthly, in terms of the supporting role of research in scientific development, this includes how to optimize the economic structure and boost economy, agricultural development, energy structure, resource conservation, recycling economy, knowledge-based society, harmonious coexistence between man and nature, balance of regional development, social harmony, national security, and international cooperation. Based on these, the role of CAS will be further identified."

Subsequently, CAS launched its strategic research on the roadmap for priority areas to 2050, which comes into eighteen categories including: energy, water resources, mineral resources, marine resources, oil and gas, population and health, agriculture, eco-environment, biomass resources, regional development, space, information, advanced manufacturing, advanced materials, nano-science, big science facilities, cross-disciplinary and frontier research, and national and public security. Over 300 CAS experts in science, technology, management and documentation & information, including about 60 CAS members, from over 80 CAS institutes joined this research.

Over one year's hard work, substantial progress has been made in each research group of the scientific disciplines. The strategic demands on priority areas in China's modernization drive to 2050 have been strengthened out; some core science problems and key technology problems been set forth; a relevant S&T roadmap been worked out based on China's reality; and eventually the strategic reports on China's S&T roadmap for eighteen priority areas to 2050 been formed. Under the circumstance, both the Editorial Committee and Writing Group, chaired by President Yongxiang Lu, have finalized the general report. The research reports are to be published in the form of CAS strategic research serial reports, entitled *Science and Technology Roadmap to China 2050: Strategic Reports of the Chinese Academy of Sciences*.

The unique feature of this strategic research is its use of S&T roadmap approach. S&T roadmap differs from the commonly used planning and technology foresight in that it includes science and technology needed for the future, the roadmap to reach the objectives, description of environmental changes, research needs, technology trends, and innovation and technology development. Scientific planning in the form of roadmap will have a clearer scientific objective, form closer links with the market, projects selected be more interactive and systematic, the solutions to the objective be defined, and the plan be more feasible. In addition, by drawing from both the foreign experience on roadmap research and domestic experience on strategic planning, we have formed our own ways of making S&T roadmap in priority areas as follows:

(1) Establishment of organization mechanism for strategic research on S&T roadmap for priority areas

The Editorial Committee is set up with the head of President Yongxiang Lu and the involvement of Chunli Bai, Erwei Shi, Xin Fang, Zhigang Li, Xiaoye Cao and Jiaofeng Pan. And the Writing Group was organized to take responsibility of the research and writing of the general report. CAS Bureau of Planning and Strategy, as the executive unit, coordinates the research, selects the scholars, identifies concrete steps and task requirements, sets forth research approaches, and organizes workshops and independent peer reviews of the research, in order to ensure the smooth progress of the strategic research on the S&T roadmap for priority areas.

(2) Setting up principles for the S&T roadmap for priority areas

The framework of roadmap research should be targeted at the national level, and divided into three steps as immediate-term (by 2020), mid-term (by 2030) and long-term (by 2050). It should cover the description of job requirements, objectives, specific tasks, research approaches, and highlight core science problems and key technology problems, which must be, in general, directional, strategic and feasible.

(3) Selection of expertise for strategic research on the S&T roadmap

Scholars in science policy, management, information and documentation, and chief scientists of the middle-aged and the young should be selected to form a special research group. The head of the group should be an outstanding scientist with a strategic vision, strong sense of responsibility and coordinative capability. In order to steer the research direction, chief scientists should be selected as the core members of the group to ensure that the strategic research in priority areas be based on the cutting-edge and frontier research. Information and documentation scholars should be engaged in each research group to guarantee the efficiency and systematization of the research through data collection and analysis. Science policy scholars should focus on the strategic demands and their feasibility.

(4) Organization of regular workshops at different levels

Workshops should be held as a leverage to identify concrete research steps and ensure its smooth progress. Five workshops have been organized consecutively in the following forms:

High-level Workshop on S&T Strategies. Three workshops on S&T strategies have been organized in October, 2007, December, 2007, and June, 2008, respectively, with the participation of research group heads in eighteen priority areas, chief scholars, and relevant top CAS management members. Information has been exchanged, and consensus been reached to ensure research directions. During the workshops, President Yongxiang Lu pinpointed the significance, necessity and possibility of the roadmap research, and commented on the work of each research groups, thus pushing the research forward.

Special workshops. The Editorial Committee invited science policy scholars to the special workshops to discuss the eight basic and strategic systems for China's socio-economic development. Perspectives on China's science-driven modernization to 2050 and characteristics and objectives of the eight systems have been outlined, and twenty-two strategic S&T problems affecting the modernization have been figured out.

Research group workshops. Each research group was further divided into different research teams based on different disciplines. Group discussions, team discussions and cross-team discussions were organized for further research, occasionally with the involvement of related scholars in special topic discussions. Research group workshops have been held some 70 times.

Cross-group workshops. Cross-group and cross-disciplinary workshops were organized, with the initiation by relative research groups and coordination by Bureau of Planning and Strategies, to coordinate the research in relative disciplines.

Professional workshops. These workshops were held to have the suggestions and advices of both domestic and international professionals over the development and strategies in related disciplines.

(5) Establishment of a peer review mechanism for the roadmap research

To ensure the quality of research reports and enhance coordination among different disciplines, a workshop on the peer review of strategic research on the S&T roadmap was organized by CAS Bureau of Planning and Strategy, in November, 2008, bringing together of about 30 peer review experts and 50 research group scholars. The review was made in four different categories, namely, resources and environment, strategic high-technology, bio-science & technology, and basic research. Experts listened to the reports of different research groups, commented on the general structure, what's new and existing problems, and presented their suggestions and advices. The outcomes were put in the written forms and returned to the research groups for further revisions.

(6) Establishment of a sustained mechanism for the roadmap research

To cope with the rapid change of world science and technology and national demands, a roadmap is, by nature, in need of sustained study, and should be revised once in every 3–5 years. Therefore, a panel of science policy scholars should be formed to keep a constant watch on the priority areas and key S&T problems for the nation's long-term benefits and make further study in this regard. And hopefully, more science policy scholars will be trained out of the research process.

The serial reports by CAS have their contents firmly based on China's reality while keeping the future in view. The work is a crystallization of the scholars' wisdom, written in a careful and scrupulous manner. Herewith, our sincere gratitude goes to all the scholars engaged in the research, consultation and review. It is their joint efforts and hard work that help to enable the serial reports to be published for the public within only one year.

To precisely predict the future is extremely challenging. This strategic research covered a wide range of areas and time, and adopted new research approaches. As such, the serial reports may have its deficiency due to the limit in knowledge and assessment. We, therefore, welcome timely advice and enlightening remarks from a much wider circle of scholars around the world.

The publication of the serial reports is a new start instead of the end of the strategic research. With this, we will further our research in this regard, duly release the research results, and have the roadmap revised every ive years, in an effort to provide consultations to the state decision-makers in science, and give suggestions to science policy departments, research institutions, enterprises, and universities for their S&T policy-making. Raising the public awareness of science and technology is of great significance for China's modernization.

Writing Group of the General Report

February, 2009

Preface

Health is an important goal as well as a base for economic development, for social progress and for a harmonic society. The China's S&T mission for public health is to build up a general applicable health assurance system. To attain this milestone, we have to formulate S&T roadmap on public health based on the international scientific and technological development in the field of health and biomedicine as well as China's unique demands on public health. Therefore, the Chinese Academy of Sciences has set up a research group focused on the field of public health. The group is composed of 27 experts from biomedical and health-related institutes of CAS. The goal of this research group is to sort out China's demand in the field of the public health for the next 40 years, determine main tasks and relevant key technologies, and formulate a China's S&T roadmap in the field of public health to 2050.

The members of this research group have been assigned for particular sectors in the field of the public health according to their experts: Qishui Lin, Tao Xu, Yunyu Shi and Jun Yu responsible for the biomedical innovation system; Enkui Duan and Haibin Wang responsible for birth control and reproductive health; Xu Lin and Yan Chen responsible for nutrition and food safety; Jiarui Wu and Yan Chen responsible for chronic disease control and health management; Bing Sun, Zhiming Yuan, Fu Gao and Li Huang responsible for infectious disease prevention and control; Aike Guo, Jiangning Zhou and Xiaolan Fu responsible for cognitive neural science, psychological and mental health; Kaixian Chen, Jingkang Shen and Hualiang Jiang responsible for innovative pharma-science; Tao Xu, Jiangning Zhou, Jun Yu and Ren Lai responsible for biomedical engineering; Duanqing Pei and Ren Lai responsible for regenerative medicine. In addition, Liubin Gao and her colleagues of Shanghai Information Center for Life Sciences, CAS, provided support with respect to related documents and information. Feng Zhang, Hua Han, Liping Wang and Fudi Ni provided support for the management of the research. After more than one year's hard work by the research group, this report on the China's S&T roadmap in the field of public health to 2050 was completed.

Due to insufficient time and limited number of experts consulted, this report might need further modification and improvement in the near future. It is our wish that both domestic and foreign experts in the field of the biomedical and public health will give their criticism and comments so that this report can truly reflect the best roads for future scientific innovation to improve China's public health.

Research Group on Public Health of the Chinese Academy of Sciences

February, 2009

Contents

Abstract

Public health is tightly related to the national economic development and social progress, and is an important base for a harmonic society. The rapid development in science and technology exerts an unprecedented influence upon the field of public health. Progress made in the life science allows traditional medicine to develop into biomedicines. In the 21st century, life science, material science, information science, cognition science, complexity science and so on will all be integrated to breed major scientific breakthrough, thus bringing about important changes in the field of public health.

As a country with the largest population, China will still emphasize "birth control" measures as its basic national population policy. In terms of birth control, the present contraception methods alone are not good enough. Thus, we have to strengthen the basic research on reproductive medicine and further improve China's research system of reproductive science and reproductive health.

Properly, nutrition is one of the best strategies for guaranteeing human health and combating diseases. At present, excessive eating and deficient nutrition are two major issues concerning China's public health. To confront this challenge, there is a need to strengthen the research in nutritional science. Furthermore, food safety becomes a serious issue, and the unsafe food is one of the major threats to the public health. There is a need to develop the appropriate technologies and platforms to allow for quick detection of poisonous and hazardous substances in food. By taking advantage of modern scientific technology and establishing a food safety database, these objectives can be accomplished.

Along with our socio-economic progress comes a growing ageing population. During the past 30 years, an epidemiological infectious disease model in Chinese society has been moved to a chronic disease model. Chronic diseases, such as cancer, cardiovascular, metabolic and neurodegenerative diseases have become the major threats to the Chinese people. It is imperative to strengthen prevention and control of such major chronic diseases by focusing on preemptive measures and relying on of medical model based on prevention, prediction and intervention.

Along with global economic integration and rapid social development, quickly increasing population flow has become a major character of contemporary society in the world. As China is a country with huge population and vast areas where local infectious diseases may occur continuously, biological safety has become an important component of the national safety, we have to

set up and improve a mechanism for dealing with public health contingencies, and establish a biosafety network for surveillance and prevention of emerging infectious disease and recurrent infectious disease.

Modern social pressure and competition in Chinese society result in the increase of mental and psychological diseases. Furthermore, there is a dramatic increase in neurodegenerative diseases in the ageing society. There is a need to strengthen research in the area of brain cognitive, to understand the biological basis for morbidity of mental diseases, to perform early diagnosis and treatment collectively. This will reduce the morbidity in psychological and mental diseases among the Chinese people, increase scientific innovation capability, promote and maintain harmony between cognition and psychology.

R&D in the area of innovative pharma-science is very important for improving the capability of China's pharmaceutical industry for the international competition, and is equally important for improving the health of the population in China. We have to push ahead with the development of China's pharmaceutical industries in a relatively short period of time. While developing new synthetic drugs, we should better understand the potential properties and the mechanisms of traditional Chinese medicines by applying new methods and technologies to the life science, and by integrating Chinese and Western medicines. We should prioritize the biomedical engineering as a new growth opportunity; promote the R&D on the products of the biomedical engineering. In addition, we should forge ahead the technologies of the biomedical engineering that integrates the theories and methods of engineering, biology and medicine.

Along with stem cell technology, regenerative medicine aims at curing major diseases through repairing, replacing and strengthening damaged, a fected or defective tissues and organs in the human body. As the vital means and research core of the regenerative medicine, the stem cell research covers several fields of basic and clinical medicines. Along with development of stem cell technology, regenerative medicine, based on the repairing and regenerative capacity of the stem cell, is expected to become the third generation of the therapy method after drug therapy and operative therapy.

In summary, the mission of the S&T roadmap to address China's public health is to establish a general health assurance system by 2050. The characteristic of this health assurance system is to focus on prevention and the control of major chronic diseases, and to transform the current medical model from reliance on disease treatment to reliance on prevention. he new model needs to integrate biology, environment, psychology and society. We need to establish a world-advanced scientific assurance system covering biological safety, food safety, and healthy lifestyle. This health assurance system will promote the physical health as well as mental health nationwide. We need to build up a modern medical R&D chain, including innovative pharma-science and manufacturing of advanced medical equipment; and make China a leader in the biomedical industry in the world.

1 Trends and National Needs of China's Public Health

1.1 Current Status and Characteristic on China's Public Health

It is widely recognized among governments and public in the world that the public health has a direct influence upon economic development and social progress of countries, and it is an important base for constructing a harmonic society. Rapid development of science and technology has exerted unprecedented influences in the field of the public health, including the life span and the quality of life, the mechanism of the human body and combat against diseases. Current status and characteristic of the public health are described below.

1.1.1 Population Pressure and Ageing Society

According to UN statistical data, world population will continue to grow to 9 billion by 2050, with the most of the increase in underdeveloped countries. Thus, in the coming 40–50 years, the proportion of child-bearing women will reach 40% of the total population. By 2030, the young population aged 10–19 is estimated to grow to 1.3 billion. Strict birth-control policy adopted in China more than 30 years has effectively curbed its excessive population growth. However, the population pressure still remains high due to a large population base. It is estimated that by the fifties of this century, the population peak in China will appear at around 1.5 billion.

For nearly two hundred years, most of the developed countries have witnessed a continuous increase in the age of population [1], and the mankind moves into an ageing society. Along with rapid development of the socio-economy in China, the population age has also increased remarkably. At present, we have 143 million people aged above 60. As estimated, late forties of this century will see a peak in the ageing population: people aged above 60 will reach 430 million, making up 30% of the total population [2].

1.1.2 Reproductive Health Faces Challenges

Reproductive health has become an important global issue in the field of the public health. At the 2005 World Summit Meeting and the 60th UN General Assembly, it was agreed that the goals of promoting reproductive health should be included in the UN millennial objective. The Chinese government also attaches great importance to the research on population control and reproductive health. In the "Outline of China's mid and long-term scientific and technological development plan", the safe contraception and birth-defect prevention are listed as the first of five priority subjects in the field of the public health.

The contraception measures in the world have been adopted at 64% by 2005, but it was not evenly distributed, and about 400 million married women did not take any contraceptive measure. On the other hand, there exists a serious problem of continuously increasing infertility rate in the world. Such couples make up 15% in developed countries, and even approach to 30% in a number of European countries. In China, such population has also increased greatly, from less than 3% in the seventies of last century to 8–10% at present.

Birth defects include congenital malformation as well as congenital mental retardation and inherited metabolic disease. At present, the birth-defect rate in China is as high as 5%, thus causing a heavy burden to the society and families. Birth defect has become one of the main causes for infant mortality and children/adult disability in China.

1.1.3 Nutrition-related Health and Food Safety Issues Becoming Increasingly Important

Food nutrition is a vital issue for the people's livelihood and their descendents' health. Maintaining a healthy diet and lifestyle is internationally recognized as an effective strategy and economical policy for preventing chronic diseases such as cardiovascular disease, diabetes type II and malignant tumors. Chinese government has always attached great importance to the improvement of nutrition and health for the Chinese people, and in 1992, it signed the "World's declaration of nutrition" and "World's nutritive action plan". he importance of these reforms recently promulgated by the State Council emphasizes the subject of "advocating healthy and civilized lifestyle and promoting properly nutrition for the public".

Like many other developing countries, China now faced the challenges of both excessive and deficient nutrition. Within dozens of years, China has been transformed and adapted a style of Western-like high fat diet, which took 200 years for Western countries to adapt. Excessive eating and reduction of physical activities is now the main reason for rapid prevalence of obesity, hypertension, type II diabetes, cardiovascular disease and some tumors [3,4]. On the other hand, malnutrition remains to be a major problem of health in the poverty-stricken areas.

Food safety in China becomes a serious problem, since the country faces the food contamination by microbes or residual pesticides, as well as environmental pollutions. In the meantime, anti-nutritional factors, transgenic food and food supplements lack full safety assessment. All of these problems constitute the major challenges to the food safety.

1.1.4 Disease Spectrum has been Changed

Thanks to social progress, scientific and technological development, the scope and degree of harmful to people's health caused by infectious diseases or puerperal and perinatal diseases have decreased considerably, which are the major threats to human being in the early stages of civilization. While the chronic diseases such as cancer, cardiovascular, metabolic and neurological diseases have become the major threats to mankind. Based on a report on the chronic diseases in 2006, the World Health Organization pointed out that the number of people who die of chronic diseases already made up 60% of the total number of deaths. To make the matters worse, this figure is set to increase rapidly, by about 17% in the coming 10 years [5]. Chronic diseases have become the major causes of death for both urban and rural inhabitants. In many poverty-stricken counties in China, the death resulted from the chronic diseases reaches as high as 60% [6].

Chronic diseases are mostly life-long diseases with bad prognosis, often accompanied by severe complications, thus greatly decreasing the quality of life of inflicted patients. Therefore, the chronic diseases significantly affect the health of the working population in China. For example, about half of patients seeing doctors in 2003 belonged to malignant tumors, cerebrovascular related diseases, heart disease, hypertension and diabetes [6].

Ageing population leads to a considerable increase of neurodegenerative diseases, which is now the fourth threat of older people's health after cardiovascular/cerebrovascular disease, cancer and stroke. In the meanwhile, due to rapid economic development, accelerated social tempo, sharpened social competition, the increase of pressure for work and study, as well as changes in spiritual activities, morbidity of mental diseases has gone up remarkably. Therefore, the mental diseases now stand as the number one in terms of total disease-burden, making up one fifth of the total burden of all kinds of diseases.

We are now in the age of information with internet, wireless communication and other modern information-technologies. Internet related behaviors become an important part of people's daily life. The number of people using the internet in China have been reached 298 millions [7].These kinds of new behavior changes in the information society result in the new cognitive or mental problems such as the internet addiction. It was reported that the number of internet-addiction people in China in 2007 reached 8 millions.

1.1.5 Infectious Diseases Remain a Serious Challenge

Despite of the great success in the battle against infectious diseases, the globalization, the changes in the ecological environment and economic development, as well as terrorism and other social unstable factors, researchers as well as the whole society have always paid great attention to the harm of emerging and recurrent infectious disease. The outburst of SARS caused by a new coronavirus in China and other countries in 2003 resulted in tremendous economic losses and social negative effect to many countries, while in recent years the whole world has been highly alert on the potential danger of prevalence of the avian and human influenza.

Despite the great progress achieved in understanding and treating infectious diseases such as hepatitis and AIDS, no highly effective therapies have been developed. Since these viruses have strong genetic variability, their infection mechanism is still not well understood. The occurrence of tubercle bacillus that is capable of resisting various antibiotics has lead to a new outbreak of tuberculosis. Since there is lack of effective therapies for treating tuberculosis, prevention and control of these infectious diseases pose a new challenge to us.

1.2 Influence of the Modern Science and Technology and the Trends on Public Health

Life science has been rapid developed and made great influence in the scope of natural sciences since 1950's. In the coming 20–30 years, mankind will achieve major progress in the understanding of the origin and evolution of life, structural and functional development of the brain and nerves. The progress regarding the subjects of genomics, proteomics and bioinformatics will enable scientists to have a better understanding of inheritance, growing and ageing, metabolism, immunity, ecology, evolution as well as biodiversity systematically on the molecular level, thus linking and integrating macro- and micro-biology.

1.2.1 Impact of Modern Science and Technology on Public Health

The progress made in the field of life science has lead to a better understanding of health and diseases. Modern biological disciplines such as molecular biology, cell biology, genetics and immunology, has integrated with clinical research and created new disciplines, including medical genetics, biomedical engineering and immunological therapeutics. Therefore, National Institutes of Health in the US has located molecular biology, cell biology, genetics, immunology and other biological disciplines into the category of biomedicine so that basic research of life science and medical research could be more closely linked and uniformly supported.

The quick development of the life science in the 20th century has beneﬁted from the integration of different fields such as physics, chemistry and mathematics. Through physical and chemical means, scientists have established modern molecular biology, discovered that DNA is a genetic material, established the principles of gene expression and regulation, and developed technologies for making recombinant DNA, thus laying a solid foundation for further research in the entire field of public health. Advancement in DNA sequencing techniques led to the successful sequencing of the whole human genome, which can now be used to understand the genetic basis of diseases and will undoubtedly lead to the development of new medicines that will benefit the population at large.

Through successful application of technologies in the field of public health such as molecular imaging technology, scientists have brought about a revolution in the field for perception of the human body. The contribution of chemical technology is seen in the rapid development in the field of chemical biology for understanding of signal transduction pathways, as well as the regulation of living processes by small molecular compounds. The invention and maturity of micro detection technique discloses the life complexity. The combination of medicinal chemistry and genomics is now giving rise to new concepts and platform technologies for development of new drugs.

1.2.2 Trends of Science and Technology on Public Health

In the last half century, science and technology has played a very important role in respect to prevention, diagnosis, therapy and rehabilitation of diseases, and promoted the modernization of medicine, thus generating two major high-tech pillar industries of the modern medical system – biomedical engineering and pharmaceutical industry. On the one hand, demands in the public health give a great impetus for the development and application of new technologies. On the other hand, breakthroughs in new technologies provide good solutions for the progress in the field of the public health. Focusing on the development of science and technology should be a priority for the public health.

The first emphasis should be on the development and improvement of research technologies of life science based on physics and chemistry, including synchronous radiation and nuclear magnetic resonance technologies, and cryo-electron microscopy for measuring the structures of macromolecules; the monomolecular measurement and manipulation technology; synthetic biological technology for synthesizing genes through micro fluid chip; high-throughput and low-cost genomic sequencing technology; the genetic manipulation technology as well as the molecular markers *in vivo* and molecular imaging technology. Furthermore, the involvement of information technology helps to greatly improve the data acquisition and processing ability in life science; and automatic-analysis technology and mathematical models will change the means and methods of life science in a revolutionary way.

A new frontier in life science is stem cell research, which will not only integrate the progress already achieved in the other major disciplines in the field of life science, but also create new model and means for disease diagnosis and therapy – a major issue in the field of the public health. The field of stem cell research will provide a new opportunity for the improvements on the public health.

Another important growing area in the future for life science research is in the field of brain science, and its key indication lies in the transformation from human exploration of the external world to its exploration of human itself, from exploration of material world to exploration of the spiritual world. Through generations of technical improvement, brain science can now give answers to a considerable number of questions regarding consciousness, but there still remains much to learn about the human mind/brain.

In recent years, there are rapid progress in international development of drug innovation. First, new disciplines of life science, such as genomics, proteomics, biological chip, transgenic animal and biological informatics, have been combined with pharmaceutical research. The aim is now finding and verifying new drug-targets and studying the e ficacy of drugs. Second, emerging new scientific disciplines are quickly integrated into the drug discovery process.

1.2.3 Transformation of Biomedicine

Along with an increasingly closer connection between modern biology and clinical medicine, basic research, applied research and industrial R&D are combined at high speed. In the future, basic biological research and clinical application research will be more closely related, and research results will be industrialized at a more rapid speed. In the past, a successful translation from a new discovery in a laboratory (publication of articles or patents) to clinical application needs 4–50 years, averaging 17 years [8]. To strengthen the marriage between clinical research and basic research, the USA and UK, the countries with the fastest development in life science and medical science, present a new development model for biomedicine called translational research, characterized by integration of basic biological research and clinical application where clinical demands always play an important part from the beginning of research as well as all later subsequent stages.

As life is a sophisticated networked system, exploring the essence of life and disease from the perspective of a system has become a new international frontier in the field of life science. In recent years, the rapid development of systems biology, a newly emerging subject on complicated biological systems–provides new ideas and methods for understanding/treating complicated diseases like tumor and diabetes. Systems biology is consistent with the general ideas of traditional Chinese medicine, thus the development of the systems biology in China provides an opportunity for the modernization of traditional Chinese medicine.

1.3 The Needs of China's Public Health

Based on the major trends in the field of the public health as well as the progress achieved in life science, the following strategic needs will be taken into account in the field of the public health in China.

1.3.1 The Needs on Improving China's Innovative Ability in Biomedicine

Although the life science in China has developed remarkably and the ranking in the clinical medical research in China has risen from the 23rd in 2003 to 17th in 2005, there is still a big gap when compared with most developed countries. Therefore, the support for life science in China must be strengthened in order to rapidly improve the innovative ability in biomedicine. Furthermore, the future progress in life science will encourage multidisciplinary research between biologists and those scientists working on other subjects such as mathematics, physics and chemistry, since life science is now at a new stage where inter-disciplinary support is needed for its further development.

The key points for improving China's innovative ability in biomedicine are to strengthen the basic research in life science. The field of the public health should prioritize the basic researches in molecular biology, cell biology and developmental biology and so on. Attention should be given to understand the relationship between epigenetic regulation and the diseases, the structures and functions of non-coding RNA, as well as the self-renewal and directional differentiation of stem cells. Moreover, attention should be paid to the development of newly emerging fields such as systems biology and synthetic biology so as to make major breakthroughs in the frontier areas of life science.

1.3.2 The Needs on Controlling Population and Improving Birth Quality

As a country with the largest population, China implements its basic national policy on birth control. Present contraception methods alone, is not adequate to meet the requirements of reproductive health. It is necessary to strengthen basic research in reproductive medicine and develop a new generation of safe, effective and convenient contraception methods. Furthermore, we have to take into account the individual differences when responding to contraceptives. Different cultures and economic backgrounds also determine the choices of fertility regulation.

While controlling the number of births, we need to improve the quality of reproductive health. Intensified researches and key techniques in the field of reproduction and developmental biology will help reduce the number of defects in newborns and improve the level of prepotency. Furthermore, in view of the continual increase in the infertility rate in the world, we have to strengthen auxiliary reproductive technologies to prevent and cure infertility.

1.3.3 The Needs on Public Health and Physical-mental Health

Major chronic diseases such as cancer, cardiovascular, cerebrovascular, metabolic and neurological diseases have become the major menaces for the Chinese population. Along with the socio-economic development in China and the increase of the ageing population, the threats of chronic diseases must be significantly increased. The strategic needs in the public health is to strengthen prevention and control of these chronic diseases, focus on preventive measures, and push ahead with the strategic transformation of medical model from past reliance on disease treatment to reliance on prevention, prediction and intervention.

Along with tremendous changes in social culture such as rapid the development of science and technology, neurological and mental diseases represented by depression and neuro-degenerative diseases become an epidemic disease of the 21st century. It has become an imperative demand of the nation to study the fundamental course of the brain and acts, determine the genetic and environmental factors related to behavior and mental disorder, solve the grave social problem of cognitive, behavior and mental disorder and realize individual physical and mental health.

Food is the physical base on which human existence relies; it is also the physical base for the health of the human body. As a developing country, China is still faced with dual challenge of nutrient imbalance and deficiency. Therefore, we have to rapidly improve the nutritious research so that the nutrition science can satisfy the requirements on the public health and disease prevention, and provide the nutrient health of the people.

1.3.4 The Needs on Guaranteeing Biological and Food Safety

Along with global economic integration and rapid social development, the growth of internal and external population low to and from various countries is becoming a major characteristic of contemporary society. Furthermore, struggle against international terrorism is now a serious issue. All these factors make biological safety an important part of national security. here is a need to establish and improve current contingency plans for public health in the event of a terrorist attack. The country needs to improve the quality of surveillance equipments and develop a network for biological safety, and raise our capacity for dealing with public security crises.

After promulgation of the "Food hygiene law of the People's Republic of China", the Chinese government implements food hygiene supervision regulations, thus integrating food safety into legal management. However, the food safety in China is faced with severe problems. At present, food-borne diseases is the primary factor affecting public health, and the potential menace for new biological and chemical pollutants in the food toward health is a new problem that should not be ignored. Furthermore, applications of new food technologies post a new challenge to food safety. Therefore, it is imperative to strengthen food safety research.

1.3.5 The Needs on Developing Modern Medical Industry

The stimulation of socio-economic development in life science is largely seen in the medical industry. At present, about 60% of all biological researches are in the area of medical sciences for the development of new drugs or improvement of conventional medicines. The total output of the medical industry in China makes up only around 2% of the total output of the country, and around 7% of the total output of the medical industry of the whole world. It is important for the medical industry in China to develop a number of "blockbuster" drugs in the forthcoming period.

The biomedical engineering industry is currently centralizing and integrating life science, physics, chemistry and engineering technology. The biomedical engineering industry and the pharmaceutical industry constitute two major parts of the modern medical industrial system. The industries stimulated by them are becoming more and more important in the national industrial economy. However, compared with developed countries, the medical apparatus enterprises in China are confined to a small scale, singular product with low technological level, and their international market shares are below 2%. Therefore, it is an urgent issue that the medical apparatus industry improves its R&D ability, upgrades the old products and raises the technological level of the products in the forthcoming period.

Traditional Chinese medicine has its own characteristics and advantages in the research field of the public health in China, and plays an important role in the respect therapy of complex chronic diseases as well as medical services in the rural areas. We should study sub-health and complex chronic diseases by using modern biological means as well as the traditional Chinese medicine characterized with integrity and systematization, so that the convergence of Eastern and Western medicines may be realized step by step in the near future.

2 Overview of the China's S&T Roadmap on Public Health to 2050

By analyzing the trends of science and technology in biomedicine and the national needs in the public health, Research Group on Public Health of Chinese Academy of Sciences depict a S&T roadmap in the public health from 2010 to 2050. To realize the grand challenges in the public health areas within the coming years, we have proposed to develop the new scientific theories and key technologies within next 40 years. Then, we can build up a general applicable health assurance system based on these new developments of life science and technology, which will provide the better solutions for protecting of health and treating diseases of Chinese people.

2.1 General Strategies of the Roadmap

The mission of the China's S&T roadmap on public health is to build up a general applicable health assurance system by around 2050. his general applicable health assurance system must have the following characteristics: a focus on prevention and control of major chronic diseases, a transition away from therapy-oriented medicine to a medical system based on predictive intervention, and a transition from using single biomedicine to an approach that integrates biology, environment, psychology and society. This type of world-class scientific assurance system will provide biological safety and food safety as well as promote healthy lifestyles. It will include the establishment of a protection system to deal effectively with sudden public health incidents and biological safety issues, and will have securing the physical and mental health of the whole population as its goal. Other goals include creating a large-scale pharmaceutical R&D chain to develop innovative medicines and manufacture sophisticated medical equipment, thereby improving the international competitiveness of China's biomedical industry, and making China a strong power in the biomedical industry.

In order to achieve the mission of this general applicable health assurance system, we have divided the China's S&T roadmap on public health into three stages: the short term from 2010 to 2020, the medium term from 2021 to 2030 and the long term from 2031 to 2050. Within each term, a general developmental strategy has been well described as follows:

By around 2020, a translational research system integrating basic research and clinical applied research should be established. The key problems to be solved are the relationship between inheritance of major chronic diseases in the Chinese people and environmental factors, and mechanisms of propagation and infection of major infectious diseases. Breakthroughs should be made with respect to new methods and technologies for early diagnosis of major chronic diseases, generation of new technology for population control, as well as inspection technology for reproductive health. With respect to rapid, portable and accurate food safety inspection technology for food-borne diseases and food poisoning, we need to establish a technical and diagnostic platform for rapid inspection of common infectious diseases and emerging infectious diseases. Moreover, we have to establish a preliminary R&D system for innovative pharmaceuticals combining Chinese and Western technologies, and make breakthroughs in the field of large-scale stem-cell cultivation and directed-differentiation technology.

By around 2030, we must establish a biomedical system that integrates modern life science with traditional Chinese medicine. The key scientific problems to be solved include molecular and cellular regulation mechanisms during the course of individual development. Breakthroughs have to be made with respect to large animal transgenic and somatic cloning technologies, reproductive technology for human organs produced in other species and used for organ transplantation, and reproductive health intervention technology. We have to develop new technologies for pharmaceutical and nutrition intervention with respect to the occurrence of major chronic diseases, and set up a high-grade biological safety laboratory, a standard inspection laboratory network, and an advanced food safety supervision network. New technologies of personalized drug therapy will be developed and breakthroughs will be made in the field of modern biotechnology based on synthetic biology.

By around 2050, we need to build up a comprehensive medical system that integrates biology, environment, psychology and society. The key scientific problems to be solved include the basic processes of brain and behavior, and cognitive impairment. Breakthroughs should be made with respect to molecular markers for neurological and mental diseases as well as functional imaging techniques. A biological cognition, supervision and treatment system for web-addiction should be established. We have to establish a nationwide u-clinic research network and biomedical databank, and provide scientific guidelines for a healthy lifestyle that is adapted to the genetic background of the Chinese population. We have to establish a new-generation biomedical system integrating advanced instrumentation technology, nanoscale biomedical technology, minimally invasive technology and combinations of instrumentation with drugs. Refer to Charpter 1.2 for details.

According to this general strategy, this S&T roadmap consists of eight objectives: (1) biomedical innovation system; (2) population control and reproductive health; (3) nutrition and food safety; (4) chronic-disease control and health management; (5) infectious-disease control; (6) cognitive neuroscience, psychological and mental health; (7) drug development and biomedical engineering; (8) regenerative medicine. In each objective, we describe the goals, tasks and key technologies.

2.2 Overview of the Roadmap

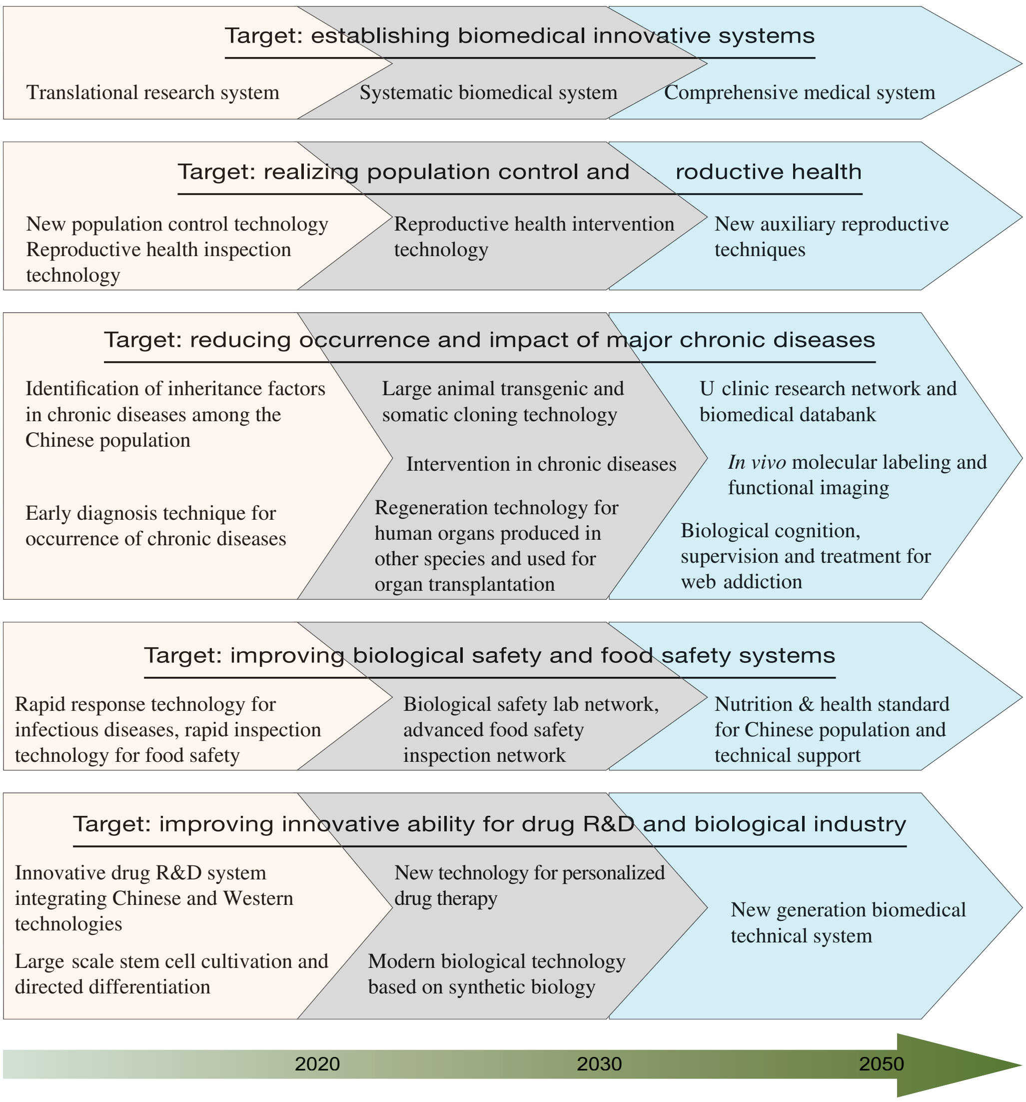

Fig. 2.1 China's S&T roadmap for improved public health to 2050

3 Biomedical Innovative System

To solve the problems confronting biomedicine and public health in China, the first priority is to strengthen our basic research. In order to achieve an all-round improvement of our scientific innovative capability in the field of biomedicine, we should pay attention to the frontier areas of life science. In the current world, the competition in comprehensive national power has obviously been advanced to the competition in the level of basic research. Basic research is an important source for the development of high-tech, the cradle for cultivating innovative talents and necessary vehicle for guaranteeing national health. The government should try its best to make major breakthroughs and foster innovation in the frontier areas of life science.

Scienti ìc development in the ìeld of public health appears a new tendency, namely, intensification of basic research and clinical application research as well as translational research. he key of future biomedical research is the establishment of a translational research system with Chinese characteristics. At present, the field of public health should put first priority on the basic research regarding the mechanism of occurrence and development of major diseases. Moreover, we should organize talented people from different disciplines to study frontier technologies of disease diagnosis and treatment as well as new instruments and new materials, thus accomplishing the transition from tracking research to innovation research in the biomedicine ìeld gradually.

3.1 Goals

Short-term goals(2010–2020): strengthen the foundations of basic research on life science related to biomedicine to improve the comprehensive power of innovation continuously; set up some interdisciplinary biomedical research centers to improve our innovative capability in biomedicine; establish a nationwide disease prevention and alarm system to respond to various biomedical contingencies; form a batch of transitional research centers and research networks of Chinese characteristics combining closely research institutions and hospitals to raise the overall transitional capacity of our biomedical research.

Medium-term goals(2021–2030): build up some international first-class basic research bases on life science related to biomedicine; make major innovation in the respect of biomedical research as well as frontier technologies of disease diagnosis and therapy including new instruments and new materials; establish international first-class disease prevention and alarm systems; form a biomedicine research system based on systems biology to make clinical research adapted to and satisfy the requirement for the development of life science.

Long-term goals(2031–2050): based on scientific and technological innovation in the field of biomedicine, build up a generally applicable health assurance system satisfying the requirement of the public of China ; transform the medical model from reliance on disease treatment to prediction and prevention, from a single biomedicine model to a new model converging on biology, environment, psychology and society.

3.2 Tasks

The key missions for establishing a biomedical innovation system are to establish and improve national laboratories and key laboratories relating to life science, medical field and public health and set up some inter-disciplinary biomedical research centers; aiming at the strategic goals in the field of public health, carry out basic, strategic and perspective studies to yield ground-breaking discoveries with respect to the mechanisms of life activities and disease occurrence/development mechanisms; develop a batch of originally innovative high technologies.

We will establish translational research centers – research complex that integrate research institutions and hospitals, thus forming a national translational research network to connect closely pathogenesis with such links of diagnosis, prevention and therapy; develop new biomedical technologies satisfying the need for early diagnosis and personalized ther py; set up a medical ethics system both conforming to international standards and adapted to the circumstances in China; establishing clinical or community population sample acquisition and application system that can meets the research requirements; set up high-quality sample chambers and databases; build up nationwide digital medical system.

3.3 Technologies

3.3.1 Frontier Technologies of Life Science Relating to Public Health

In the field of life science, we have to recognize the mechanism of normal physiological activities at the levels of molecule, cell, organisms, thus recognizing the causes for disease occurrence and development. herefore, the key point is to make breakthroughs in the methodology and technology of life science, which will bring about development of the discipline as well as biomedical instruments and reagent industry.

Technology of structural biology: The technology of structural biology is the one for measuring the biological macromolecular 3-dimensional structure, and provides a basic structural model for deep understanding of the essence of life phenomenon from molecular level and offers key theoretical grounds for drug design, screening and development. Future development of structural biology will yield breakthrough progress in the respects of hardware upgrading, flow integration, technical maturity and method innovation. With respect to sample preparation, a series of new techniques and methods will appear in the research of membrane protein, protein complex and biological supra-molecular protein complex, including new recombinant expression system, new extraction and purification methods and new crystallization technique. In the respect of crystal diffraction technique, automatic synchronous radiation technique of high brightness, microfocus and high stability will become a in the research of new techniques and methods of structural biology. Furthermore, single molecule imaging technique based on free electron laser of X-ray is expected to overcome the bottleneck of biological macromolecular crystallization. With respect to nuclear magnetic resonance spectrum, efforts will be concentrated on structural measurement of protein in the instantaneous unstable complex and living cells and the study of dynamic changes in protein structure. he maturity of solid-phase nuclear magnetic technique will give a strong impetus to the analysis of the 3-dimensional structure of membrane protein. In respect to 3-dimensional reconstruction of high-resolution electron microscopes, the imaging technique of highly stable high-resolution field emission electron microscopes will further improve the resolution of 3-dimensional reconstruction; the development of automatic data collection and new algorithm will make it possible to use cryo-electron-microscopy to analyze 3-dimensional structure of membrane protein, supramolecular complex, molecular machineries and sub-cellular organization at nanometer resolution; the study and application of new imaging theory will possibly raise the resolution of 3-dimensional reconstruction nearly to the level of atomic resolution. Moreover, various new labeling techniques will also greatly move forward with the development of structural biology.

Real-time quantitative molecular imaging technique at high temporal and spatial resolution: Present imaging technique involves the scope from basic research to clinical diagnosis and from monomolecular level to the level of tissues and organs, and its development tendency is a continuous increase in resolution. Along with the development of synchronous radiation light source of high brightness, corresponding optical and nanometer manufacturing technology will endow X-ray imaging with much higher resolution as well as penetration, thus finding even wider application in life science. We are expected to see rapid growth in soft X-ray imaging. The hot spot of optical imaging techniques lies in the single molecule detection and optical imaging techniques of high resolution. Techniques surpassing the optical diffraction limit are emerging, bringing the resolution of the optical microscope from 200 nanometers to tens of nanometers step by step and aiming at nanometer resolution for the next stage. Another goal is high resolution imaging at 3 dimensions with multiple labels in living cells. Magnetic resonance imaging (MRI), a technique of rapid development and wide application in biomedicine, will develop from structural imaging to imaging of various functional indexes in the future. As far as observation indexes are concerned, along with the development of MRI technique of ultra-high magnetic field (above 7T), the single proton imaging will give place to multiple-nucleus, thus greatly extending the capability for observing functional processes of organisms. Moreover, while developing imaging techniques, we have to pay enough attention to molecular labeling technique (fluorescent label, isotopic label, spin label, quantum dot label, etc.). Non-labeling imaging techniques will also be worth developing.

Single molecule manipulation, assembling and inspection technique: The single molecule manipulation, assembling and inspection techniques have become an interdisciplinary subject between the field of life science as well as such subjects as chemistry, physics, engineering, materials and electronics. To make technological breakthrough, we have to apply advanced characterization means (scanning probe, combination of near-field optical microscopes, atom force microscopy, new laser tweezers technique, macro-nanotechnology, etc.) to life science, in expectation of breakthroughs with respect to key technologies like biological molecular complex assembling and nanometer molecular apparatus of directional monomolecular manipulation. Furthermore, the present micro-array technology is expected to be extended to the nanometer level (by means of atomic force dip-pen printing technology). New intelligent apparatus-manufacturing platforms will be established, and various types of nanometer robots will be made for disease treatment, so that early disease diagnosis and prevention may become more reliable.

Omics technology: Genomics technology has become a frontier subject and system engineering of life science. The new generation of genomics technology provides a powerful tool for the study of personalized genome and genetic variations related to disease susceptibility and will open up a long-expected “age of personalized therapy”. By that time, personal diagnosis, therapy, drug usage and health guidance will be realized. Proteomic technology largely includes biological separation and mass spectrometry. Development and application of proteomic technology has shifted from large-scale protein evaluation and analysis of expression spectrum to the establishment, through technological integration, of the quantitative technical platform of proteomics which are composed of high-resolution mass spectrum, multi-dimensional capillary fluid chromatography, highly efficient and stable isotope labeling and non-labeling technology and separation technology for low-abundance protein (or peptide) enrichment and sub-cellular organelles and which are adapted to biological specimens of different complexity. The metabonomics may possibly make great progress with respect to key technologies: firstly, parallel large-scale inspection platforms of high throughput. Small molecular separation evaluation platforms of even stronger resolution and higher throughput will be formed by means of combination of super-effective liquid chromatography and gas chromatography as well as high-resolution mass spectrum. Along with introduction of ultrahigh-field NMR and the combination of mass spectrum and NMR, high-performance technical platforms may possibly possess higher evaluation and separation capability on a larger inspection scale. Secondly, development of the data analysis system, focusing on improvement of the analysis and modeling capability relating to the information about the large amount of constituent metabolites in the complex mixed systems.

Micro-array technology: The micro-array technology is the one by which semi-conductor materials and elements as well as micro-processing techniques are used in micro space or on micro surface to integrate molecular and micro-electronic testing systems for DNA, protein and other organisms for the purpose of interpreting and measuring the processes of bio-chemical reactions, so that DNA sequential variations, interaction between nucleic acid molecules, as well as dynamic combination and reaction between receptor-ligand and antibody-antigen and other biological active materials can be tested and analyzed quickly and efficiently. Development and comprehensive application of various micro-array technologies will greatly improve our diagnosis capability for various diseases, and realize early diagnosis and prevention as well as reduction and delay of disease occurrence and development.

3.3.2 Technology of Systems Biology

Systems biology, an emerging discipline of the post-genome era, studies the means, network, functional system and dynamic characteristics of gene interaction with the help of new interdisciplinary techniques and methods, thus disclosing the basic design and control principles of the life system. Systems biology not only enables us to get a full understanding of all the components of the complex life system and their dynamic relationship, but also predicts its trends of changes when it is under external interference. Systems biology requires that biologists make biological study on the cellular or modular biological systems, physicians and chemists study the mechanism of interactions and develop new testing techniques and methods, mathematicians build up mathematical models describing biological systems, computer scientists develop techniques of storage, processing and representation of massive data as well as algorithms and programs for the purpose of emulation of complex systems, engineers and technicians develop new types of experimental instruments.

3.3.3 New Materials and New Formulations in the Biomedicine Field

For future biomedical materials, their own physical and chemical properties and biological safety will be stressed, but what's more important, their biological structure and functions will be described so as to reconstruct or repair damaged human tissues or organs. Our research on biological materials, relying on a good base, has made certain achievements in the aspects of recombination of materials, blood purification, biological compatibility and surface modification, and may in the future achieve influential progress in the fields of biological nanometer materials (such as material for controlled drug delivery and release, nanometer quantum dot, nanometer scaffold material, nanometer membrane and nanometer surface decorative material), blood purification material, compound biological material and biological compatibility. Furthermore, chemical treatment of material surface, physical surface modification and biological modification will be the main subjects which we will emphasize for a long time in our research of biological materials.

The urgent mission in our development of biomedical formulations is to strengthen terminal purification technique as well as the technique of large-scale preparation of biochemical formulations and drug formulations. In the meanwhile, we have to vigorously develop gene and cell engineering products, and solve problems of production process and quality standards regarding recombinant medical enzyme, diagnosis enzyme, anti-body and vaccine. In the respect of basic research, we should develop labeling molecules with special physical and chemical properties (such as fluorescent molecules of small size, low bleaching rate and photo-switchable or photo–activatable activities, paramagnetic probe), intended to label large biological molecules so as to greatly improve the sensitivity and resolution of optical imaging, NMR and paramagnetic resonance.

3.3.4 Technology of Synthetic Biology

Synthetic biology is a result of disciplinary intersection between genomics, biological informatics and systems biology since the implementation of the human genomics project, aiming at synthesizing functional gene modules in the way of high throughput gene synthesis for the purpose of restructuring living bodies finally. Representing the next generation of biological technology, synthetic biology is certain to exert major influence upon the development of China biotechnological industry. Synthetic biology will have wide application in many fields including public health. Among the examples are realization of mass production of drugs and vaccines by means of new live organisms, manufacturing and construction of artificial life systems which do not exist in nature, curing diseases by repairing cellular functions, eliminating tumors, stimulating cell growth and regenerating some decisive cells.

3.3.5 Animal Model Used for Research on Human Diseases

In the future, we should strengthen the development of animal models which are closest to mankind at the physiological and pathological level and most heritable and physiologically operable, such as those of pigs or primates, and develop relevant generic operational technologies specific to such large animals, such as establishment of experimental pig of inbred strain (pure strain) and establishment of various types of organ transplantation and disease models. As it is mostly impossible to study directly cells damaged in diseases, it is necessary to development cellular models formed by directionally differentiated stem cells, so that these cells may simulate diseases to help understand pathogenesis and develop preventive methods.

3.3.6 Nano-biomedical Technology

Nano-biomedical technology includes establishment of new types of materials, drugs and ultra-micro devices based on nanometer chemical principle and structure by which we can comprehend the interaction within living cells at the nanometer level, absorbable and metabolizable nano-material, nanostructure of organisms, mono-cellular diagnosis of ultrahigh sensitivity, sustained release of nanotechnological drugs and nanometer targeting drugs. For instance, establishment of new types of nanometer surface materials, simulation of micro environment for growth of various types of cells, induction of directed differentiation of multipotent stem cells through solid surface technology, induction of formation of tissues and organs by use of nanotechnology, tracing and regulation *in vivo* as well as improvement of the success rate of transplantation of tissues and organs all fall in the category of frontier research.

3.3.7 Database of Biomedical Resource and Data

Database of resource and data for biomedical and clinic medical research based on modern internet technologies should be set up, with emphasis on the establishment of database systems relating to the research of public health and diseases, such as gene polymorphism of China public, the gene expression spectrum of the physiological and pathological status of the mankind and model animals, epigenetic inheritance regulation and changes in the non-coded area. We should establish a complete database of resource and data for human inheritance, small molecules and natural products, and collect all information about a candidate drug, such as extracorporeal experimental data, preclinical drug, drug metabolism, pharmacokinetics, toxicology, human pharmacokinetics, human drug efficacy and safety and interaction between drugs. We should develop digital medical imaging, physiological and pathological specimen database and perfect information and data visualization technology.

3.3.8 Virtual Clinical and Health Research Network

We should push ahead with an all-round cooperation between medical informatization and biomedical research, and establish digital data exchange systems for individual genetics, normal physiological health status, and clinical diagnosis and treatment. We should create an “U” research network for biomedicine, develop a wireless remote research and therapy technologies, establish an electronic medical record and informatized public health management system as well as powerful computer models so as to acquire and integrate information about health and disease, and carry out virtual research in the emulated and pathological conditions as well as research on epidemiology and genetic relevance.

3.4 Roadmap

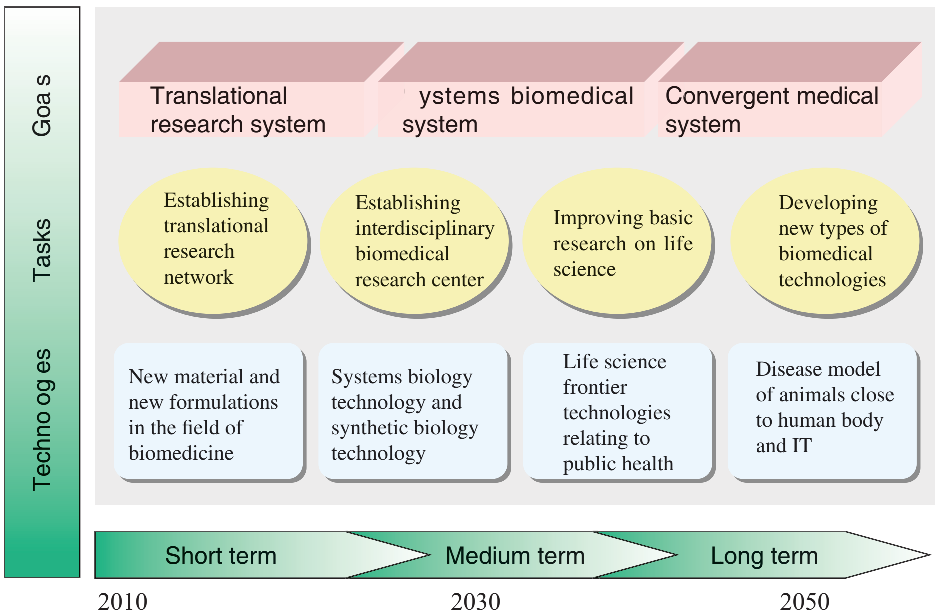

Fig. 3.1 S&T roadmap on biomedical innovative system

4 Population Control and Reproductive Health

Rapid population growth is no doubt the most striking issue restraining sustainable development in China. On the one hand, our country is faced with continuous growth of total population, on the other hand, due to environmental factors and changes in life style, the present infertility rate reaches 8%–10% of the couples at reproductive age in some areas, and this rate still keeps rising. Furthermore, birth defect and congenital disability, a trouble for many families, has become a distinct social problem. Obviously, in a considerably long period to come, our public health will be confronted with the strategic demands on control of population quantity, improvement of population quality and improvement of national level of reproductive health.

4.1 Goals

Short-term goals (2010–2020): to determine the molecular and cellular base of reproductive and developmental events related to human health; to explore the impact of environment pollution upon fertility and descendents health; to elucidate the causal mechanisms of infertility and other major diseases accompanied by reproductive aging; to develop inspection technology for birth defects and individual test chips for common reproductive diseases; to further optimize cryopreservation protocol for longtime storage of reproductive tissues and cells; to assess the mid and long-term safety of assisted reproduction technology (ART); to position new contraceptive targets through functional genomic and proteomic analysis and develop non-hormonal contraceptive pills and tools.

Medium-term goals (2021–2030): to develop reproductive health intervention technology and optimize the *in vitro* operation techniques for correcting genetic defects employing embryonic stem cells and germ stem cells combined with ART; to establish excellent tactics and methods for preventing reproductive tract infection diseases and sexually transmitted diseases; to develop a new generation of efficient, side effect-less and reversible contraceptive methods.

Long-term goals (2031–2050): to develop next generation of personalized optimal contraception technology and reproductive health test and intervention technology for better prenatal and postnatal care to further raise substantially our population quality; to realize individual whole genomic sequencing for most of the population, set up disease spectrum database, and develop more ideal ART.

4.2 Tasks

The strategic mission in the field of reproductive health of China public lies in the following respects: to explore and elucidate the regulatory mechanisms governing reproductive and developmental events aiming to lay a theoretical foundation for preventing reproduction-related diseases and developing safe, long-effective and self-controllable contraceptive medicines and tools; to study the impact and underlying mechanisms of environmental pollution upon various aspects of reproductive health, aiming to develop new intervention methods in the clinical practice; to study the pathological mechanisms for sexually transmitted diseases, establish more effective medical supervision and control systems and develop relevant preventive vaccines; to understand the nature of human reproductive ageing and, develop new types of hormone replacement therapy and related methods in the clinical treatments of ageing-resulted infertility and diseases; to study the causal mechanisms of birth defects, establish and improve inspection techniques and preventive measures of birth defects; to evaluate the potential trans-generational risk of ART operation, establish new methods and technical systems for ART safety appraisal and develop *in vitro* operation and correction technology of genetic defects employing embryonic stem cells and germ stem cells. Furthermore, we should establish information platforms for reproductive science and strengthen the formation of ethical criterion related to reproductive science.

4.3 Technologies

4.3.1 New Types of Contraceptive Technology

Contraceptives targeting ovum: we should further explore the nature of egg-sperm fertilization, and develop new contraceptive pills by preventing sperm-egg recognition and fusion during the process of fertilization without a fecting follicle development, oocyte maturation and ovulation.

Male contraceptives targeting sperm: on the basis of screening out molecules specifically expressed in sperm tails and involved in regulating sperm motility, we may able to develop male contraceptives which will not affect androgen secretions and hereditary substance at sperm head.

Contraceptives targeting blastocyst implantation: we should further disclose the molecular mechanisms governing blastocyst-uterine interactions during implantation, and develop new type of nonsteroidal "genetic contraceptives" by preventing blastocyst implantation into the maternal endometrium.

4.3.2 Cryopreservation and Thawing Technology of Reproductive Tissues/cells

Cryopreservation-thawing technique of reproductive tissues/cells: Sperm cryopreservation technique should be further improved via optimizing the cryopreservative medium and freezing procedures to maximally reduce irreversible damage on sperm membrane. The cryopreservation and thawing technique for oocytes, and particularly the *in vitro* maturation (IVM) methods for oocytes underwent cryopreservation-thawing operation should be improved so that patients suffering from ovarian ageing and related diseases or women who require late childbirth will have an opportunity to have own babies.

Blastocyst cryopreservation-thawing technique: We will develop and optimize the cryopreservation techniques for blastocysts obtained via *in vitro* fertilization (IVF) or intracytoplasmic sperm injection (ICSI) operations. In addition, quality evaluation indexes for thawed embryos should be standardized.

Cryopreservation-thawing technique for ovary tissue and testis tissues: Cryopreservation of gonadal tissues like ovum and testis is a more potent preservation form compared with sperm and ovum bank. Cryopreservation of testis tissue has been documented as a good alternative method for sperm preservation. For those who face the risk of losing their germ cells from diseases or unknown causes, it maybe an option in clinical treatments if their gonadal tissues can be cryopreserved in advance and can be used upon thawing in future to restore their fertility.

4.3.3 oocyte/embryo *in vitro* Culture and Transfer Technology

In vitro culture and mature of growing oocytes: IVM of oocytes is becoming a useful technique in clinical treatment of infertility. However, further optimization of IVM medium and cultivation schemes is required to improve the quality of IVM-derived oocytes in the aspect of the fertilization rate and subsequent embryo development rate.

Embryo transfer (ET) window: in the clinical practice, it is still a great challenge to assess the developmental status of the embryo and endometrium regarding their respective implantation potential, therefore resulting in only about 30% implantation ratio after embryo transfer in the IVF-ET cycle – a major bottleneck in the ART practice, which warrants a deep study.

Selective single-embryo transfer and multifetal pregnancy control: Multifetal pregnancy in the IVF-ET cycle often leads to low body weight and more likely to premature delivery, while a fetus obtained through single embryo transfer appears to grow stronger. In few European and American countries, the technique by which a single embryo is selected and transferred has been recently applied in a small population of ART patients. In the future, this technology will get improved upon a better understanding on the molecular basis of embryo implantation window.

4.3.4 Clinical Auxiliary Reproductive Technology Based on Micromanipulation

ICSI, the second generation ART technique based on micromanipulation, needs a very small amount of sperms to reach a fertilization rate equivalent to normal IVF, thus being a leap forward of the ART application. However, as sperm selection during the natural fertilization process is skipped over via this technology, it might possible that injected sperms may carry chromosome aberration or gene mutation, thus transmitting paternal genetic defects to the next generation. However, such shortcoming can be overcome by genetic diagnosis of ICSI sperms.

4.3.5 Genetic Diagnosis Before Embryo Implantation

Pre-implantation genetic diagnosis (PGD), the 3rd generation ART technique is a newly emerging technique developed in combination with embryo biopsy and molecular genetic diagnosis technology. Through this technique, embryos with genetic defects can be found and eliminated before transfer, thus reducing the spontaneous abortion rate, and most importantly avoiding birth of infants with genetic diseases. Since embryo biopsy is the key step in PGD operation, more efficient and less harmful embryo biopsy technologies need to be developed in the future. In addition, multiple approaches including the fluorescent *in situ* hybridization (FISH) single cell PCR inspection and comparative genomic hybridization technology (CGH) should be utilized in PGD analysis of sperm, poly body and blastomeres.

4.3.6 Safety Appraisal for ART

Along with rapid development of epigenetics, potential epigenetic influences on gametogenesis and embryogenesis processes have drawn increasing attention. Therefore, to make better long-term appraisal of the ART safety, it is important to develop new health surveillance indexes for IVF-ET fetuses, particularly in tracing and analyzing the association between variations in epigenetic status and major diseases in adulthood of ART offspring on a long time base. We should establish databases of major epidemic diseases of ART descendents in adulthood, as well as an appraisal system for the underlying molecular marks of epigenetic alterations.

4.3.7 Genetic Diagnosis and Correction Technology for Birth Defects

The prenatal chromosome examination includes conventional karyotype analysis, high-resolution banding analysis and FISH analysis. Through chromosome examination of chorionic villus cells and amniotic fluid cells, one can quite accurately judge chromosome diseases of the fetus. Moreover, we should develop screening technologies and whole genomic analysis of single nucleotide polymorphism (SNP) for prenatal pathogenic genes. In addition, we should also actively carry out prenatal interventional therapy for birth defects of known causes, including surgery therapy and gene therapy.

4.3.8 Screening Technology for Major Pregnancy-related Diseases and Reproductive Tract Disorders

We should develop strategies for early prediction, diagnosis and therapy of major pregnancy-related diseases and reproductive tract disorders, like recurrent abortion, preeclampsia, and endometrial cancer. Via genomic, proteomic and metabonomic analysis of large volumes of samples from patients with different pregnant-related diseases and reproductive tract disorders, potential molecular and cellular marks for respective diseases should be identified, which can be further used in the general survey of women to make earlier supervision and intervention for those with risks of high-prevalence diseases.

4.4 Roadmap

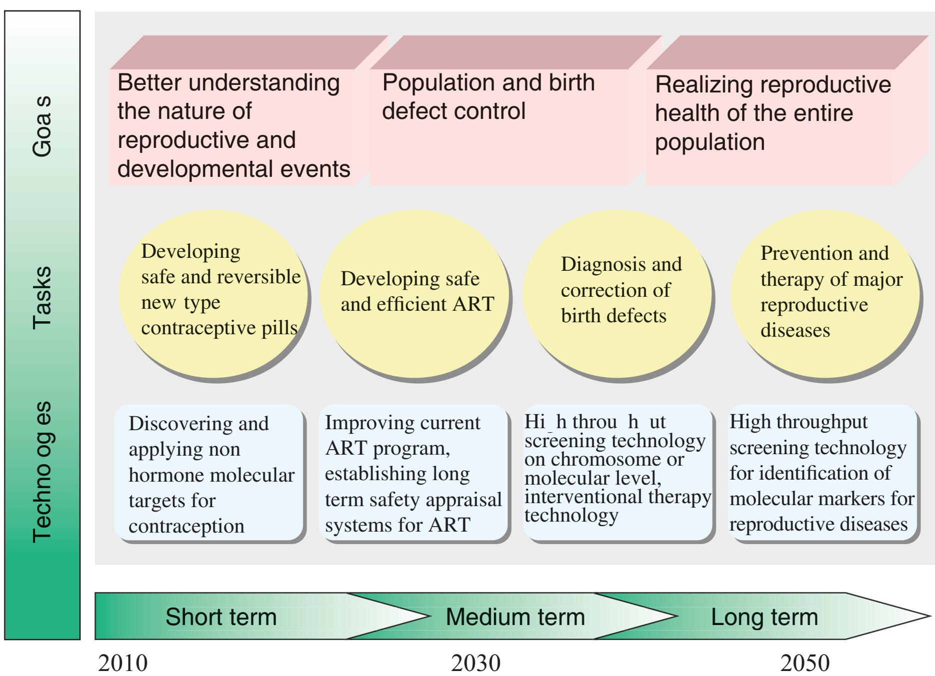

Fig. 4.1 S&T roadmap on population control and reproductive health

5 Nutrition and Food Safety

The ultimate goal of nutritional sciences is to help people to achieve an optional nutrition and health status which is one of the key elements for building a modern and harmonic society. China is currently experiencing a rapid transition in nutrition and epidemiology. Over nutrition and its related diseases has become one of major threats to public health in China, while malnutrition still remains as one of major public health concerns in poor or rural areas. Accompanied with further industrialization, urbanization and increasing aging of population in the next 5 decades, it can be expected that public nutrition will encounter more severe challenges.

With the economy globalization and rapid socio-economic development, food safety has been another major public concern in China. For instance, food-borne diseases are still one of important health risks to the public. New biological and chemical pollutants, as well as genetically engineered foods and food packaging materials, may also bring new burden for food safety. Therefore, how to keep food safely is essential not only for people's health, but also for sustained socio-economic developments.

5.1 Goals

Short-term goals (2010–2020): (1) to establish a platform and system for modern nutritional research; (2) to determine the functions, molecular and metabolic mechanisms and regulatory pathways for various nutrients and food components; (3) to develop new technologies, new methodologies and biomarkers to assess nutrition, physical activities, and metabolic status; (4) to establish nutritional surveillance, nutrition education, and food guidance as well food safety monitoring network covering both urban and rural communities; (5) to further improve Chinese food component and nutrition database; (6) to establish the nutritional recommendations and dietary guideline which are specifically suitable for Chinese genotype and metabolic phenotype; (7) to establish food security database, and develop new technology and platform for rapid detection of unsafe food; (8) to investigate acute and/or chronic toxicological mechanisms of food contaminants and food-borne diseases;

(9) to establish a preliminary monitoring and management system for food safety monitoring and risk assessment.

Medium-term goals (2021–2030): (1) to determine optimal requirements for nutrients and food component and ideal diet pattern based on different people and individual genetic susceptibility during different stages of the life cycle; (2) to establish and improve the network system covering the whole society for the surveillance of nutritional status, as well as individualized and interactive nutritional education and guidance based on advanced information and computer technology; (3) to minimize epidemic of malnutrition, over-nutrition and nutrition-related diseases; (4) to establish safe intake range of nutrients, dietary supplements, fortified and functional foods, and phytochemicals for the Chinese population according to the genetic and metabolic characteristics; (5) to further improve food contaminant monitoring and food-borne disease alert network and risk assessment system, as well as to reduce or even eradicate toxic contaminations in food.

Long-term goals(2031–2050): (1) to achieve overall improvement in healthy diet and lifestyles in China; (2) to improve the health status of pregnant women, children and elders substantially by eliminating malnutrition and over-nutrition; (3) to achieve personalized diet and nutrition recommendation, and lifelong healthcare; (4) to control food contamination and food-borne diseases completely.

5.2 Tasks

(1) The first priority is to determine the nutritional status of China public in different regions and residences, and at different stages of life, as well as the relationship among various nutritional components, dietary patterns, and health status; (2) to understand in-depth the genetic and metabolic characteristics of Chinese people, as well as the role of gut flora in food digestion, absorption and bioactivities, as well as their health implications; (3) to determine the optimal amount of nutritional requirement and physical activity, as well as scientific and optimal diet patterns, in order to improve the physical well-being of publics and individuals. In this regard, it is necessary to set up a number of longitudinal studies on nutrition, genetics and health, and to establish a research system for evaluating human nutrition and metabolic status dynamically and accurately; to update the Chinese food composition table and nutritional database continuously; (4) to establish community-based nutrition surveillance and interactive nutrition guidance network based on modern computer technologies and information technologies; (5) to determine the sensitivity and specificity of high-risk groups exposed to food and nutrients; (6) to conduct scientific research in the light of providing recommendations of nutrients and intervention strategies for the public and individuals; (7) to improve the quality of food products and food processing, and to provide healthy food with the goal

to minimize malnutrition and over-nutrition in China; (8) to implement in-depth basic research on food safety, to develop advanced technologies for food-borne diseases and hazard assessment; (9) to develop more rapid, portable and accurate food safety evaluation technologies, and to accelerate the development of major food contaminant residual control technologies; (10) to establish food safety criteria system which comply with international standards and meets the demands of China; (11) to conduct acute and chronic toxicology study and risk assessment for major toxic and hazardous substances to provide scienti ıc basis for the establishment and improvements of Chinese food safety laws and regulations.

5.3 Technologies

5.3.1 Longitudinal Study and Platform for Research in Nutrition, Genetics and Health

To establish a series of longitudinal studies on nutrition, genetics and health may allow us to follow-up different populations in the long-run. Therefore, it is possible to determine the impact of dietary pattern, life style, genetic variation, and gut flora on metabolism and health, and to explore the optimal dietary patterns and amount of nutrient intakes. Meanwhile, it is important to integrate *in vivo* with *in vitro* studies focusing on the mechanism underlying the interaction of nutrients and dietary factors with genetic variations, as well as the regulation on target cells and tissue functions. hrough a combination of a variety of advanced technologies, it is important to develop new dietary assessment and detection methods for the requirement of assessing nutritional, the impact of unhealthy dietary pattern or lifestyle on health, as well as the underlying mechanisms systematically and accurately.

5.3.2 Research Platforms and Related Technologies on Human Nutrition and Metabolism

To establish a number of "metabolism research unit on human nutrition" (Metabolic Research Unit, MRU) simulating real-life environments. The MRU usually consists of three parts: the experimental diet preparation unit, physical activity measurement unit, and experimental wards. The MRU has body composition measurement platform, metabolism measurement platform, and food ingredients and bio-sample testing platform. hese MRUs are important supplements to molecular, animal, and epidemiological studies. With the help of MRUs, it is possible to assess nutritional functions and nutrient storage status under different physiological conditions and obtain high-quality data necessary for determination of nutrient requirements and implementation of nutritional interventions accurately.

5.3.3 Public-based Nutrition Surveillance and Education Network with Modern Information Technology

Computer systems and network, mobile communication technology platform and advanced laboratory detection methods can be applied to track data on nutritional status, knowledge, attitudes, behavior, and progression of disease affecting nutritional status, nutrient-gene interaction, dynamic changes of biological markers, impacts of food contamination to health systematically and consecutively. These strategies will allow people to obtain a dynamic picture of nutritional status and disease progression in the public. With the help of integrated data, it is possible to evaluate the effects of various national nutrition policies and projects as well as to predict the future trends with nutrition surveillance. Nutrition surveillance network can also be used to provide individualized interactive health education and behavior intervention service through various media such as internet and 3G technology. he rapid information exchange and feedback can be used to improve intervention e tects.

5.3.4 Genotype Based-dietary Patterns and Nutritional Recommendation

China's current DRIs (Dietary Reference Intakes) are developed from RDA (Recommended Dietary Allowance), which is based on the assumption of a normal and homogeneous population distribution. It has been found that genetic variation may disrupt nutrient homeostasis, which may result in malnutrition or over-nutrition in certain different people or individuals. In order to meet the needs of different individuals and people with di terent genotypes, a systematic research on the impact of single nucleotide polymorphism on human nutrition and health is imperative. It is important to establish a systematic assessment system on dietary pattern and nutrient requirement for public and individuals with different genetic backgrounds, which would enable people to establish scientific basis for genotype based-food and nutrient recommendation intakes for China public and individuals.

5.3.5 Detection Technique of Hazardous Food Substance and Research for the Underlying Mechanisms

With the help of collaborative multidisciplinary research including chemical analysis, modern molecular cell biology, genomics, metabolomics and toxicology as well as a variety of models, it is feasible to conduct a comprehensive classification of current major toxic and hazardous substances at molecular, cellular and animal levels, and determine the metabolic pathways and intermediates *in vivo*, as well as the molecular mechanisms and signal transduction pathways of toxic effects. It is of great importance to develop innovative, cost-efficient, rapid detection techniques and corresponding detection kits for microbial, to establish rapid and quantitative detection and on-site rapid screening method for pesticide residues and other toxic chemical contaminations in food, and to develop detection technologies for new foods such as genetically modified foods.

5.3.6 Food Safety Risk Assessment and Early Warning Technologies

(1) To establish wide-area food contamination alerting system applicable to large and medium-sized cities; (2) to build food safety framework; (3) to establish theoretical models that can be used for food safety risk assessment and prediction; (4) to investigate chemical pollutants and biological factors risk; (5) to apply the technologies of high-resolution chromatography, mass spectrometry and metabolomics technologies in the studies of potential harmful effects of foods that does not meet food safety standards, and to screen residual markers and related biomarkers to establish warning models; (6) to develop efficient, simple, rapid detection kit or new detection equipments to enhance the detection level of contaminants and provide scientific basis for national contaminants detection standards.

5.4 Roadmap

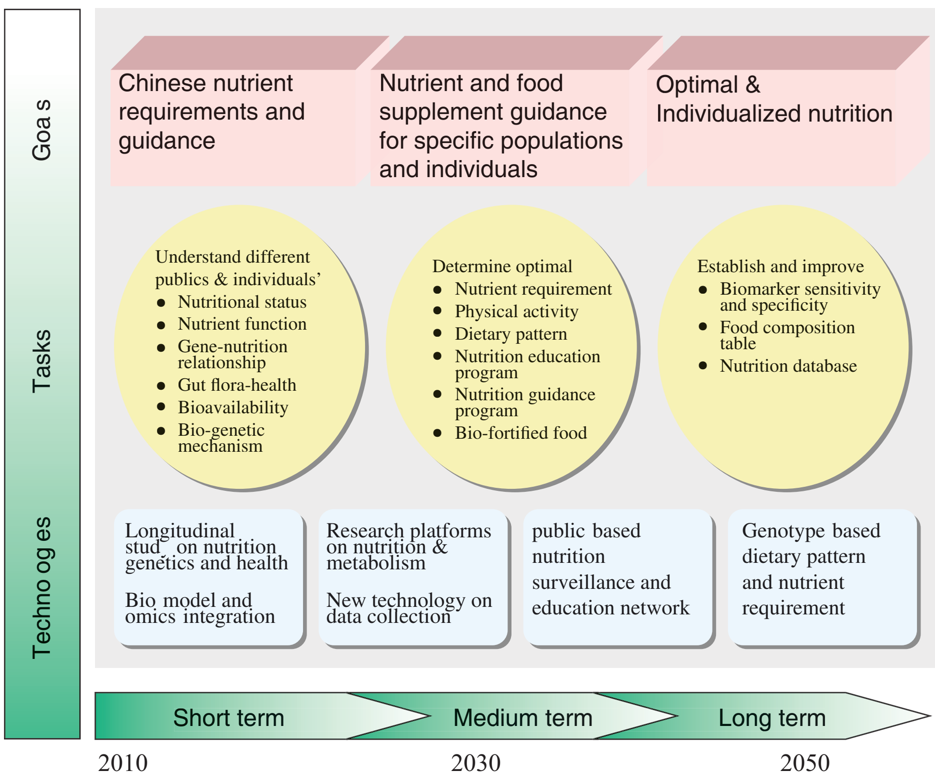

Fig. 5.1 S&T roadmap on nutrition and health

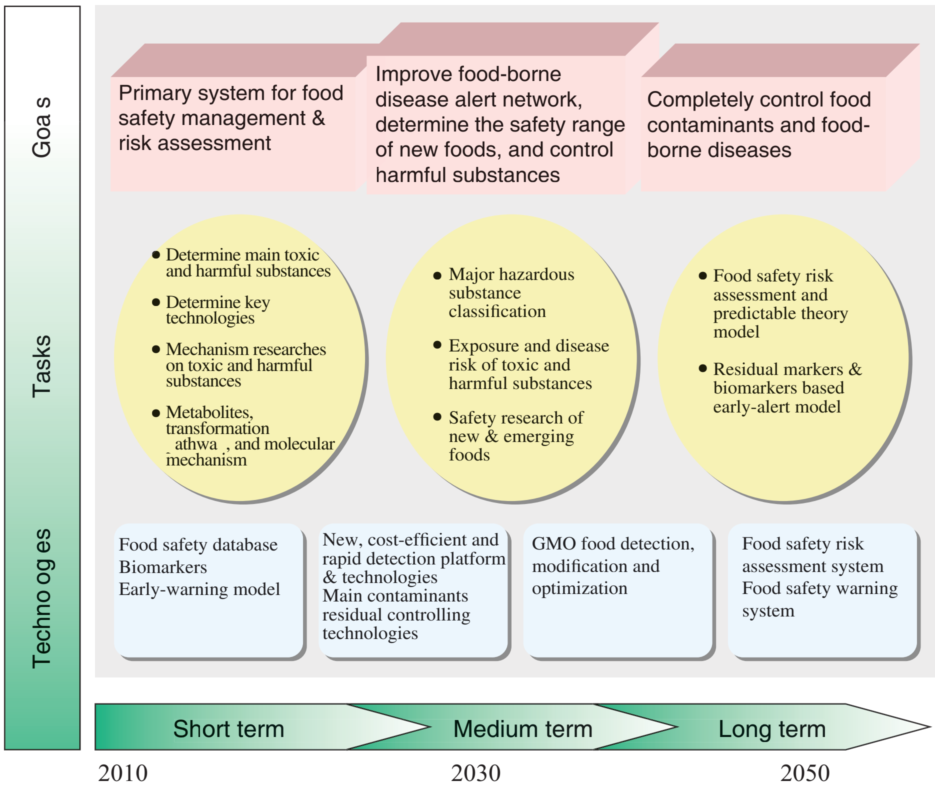

Fig. 5.2 S&T roadmap on food safety

6 Chronic Non-communicable Disease Control and Healthcare Management

Chronic non-communicable diseases such as cancer, cardiovascular diseases, metabolic disorders and neural-degenerative diseases are becoming major threats to human health worldwide. With robust growth of economy, China's epidemiology model has made the transition from infectious diseases dominated to chronic diseases as heavy ones in only a few decades. Already the major threats to the health of Chinese people now and in the future, chronic disease may become a more serious problem with sustained economic development, diet changes and a more sedentary lifestyle as well as the ageing of the population.

Chronic diseases have two major characteristics. Firstly, once people are accounted for the chronic diseases, most of the diseases will last the whole life time without complete recovery. Secondly, the complications of chronic diseases may result in high death and disability rate. Therefore, the best strategy for controlling major chronic diseases should focus on monitoring and intervening in the early stage of chronic disease's progress. In order to do so, we need to develop new diagnostic means based on molecular biomarkers to monitor physiological status of people for early stage of sub-health or chronic disease symptoms, and then subsequently intervene through diet or therapeutics. If conducted successfully, this kind of the strategies can reduce the incidence rate of major chronic diseases, slow down the progress of chronic diseases as well as reduce the death and disability rates resulted from chronic diseases.

Healthcare management means scientific, behavioral, social or environmental interventions that would lead to positive changes in people's lifestyle and hygiene habits, so much so that successful prevention and control of major chronic diseases takes place systematically while healthcare cost gets significantly reduced and healthcare resources more efficiently utilized. In the future, the focus against chronic diseases would shift forward towards prevention, and the confrontational strategy to the chronic diseases would be a combination of prevention, health promotion and therapeutic approaches. Our healthcare model is now going through a strategic shift from therapeutic-centered healthcare to one focusing on healthcare management and prevention of diseases.

6.1 Goals

Short-term goals (2010–2020): understand the mechanism of major chronic diseases including cancer, cardiovascular diseases, metabolic disorders and neural degenerative diseases; and to uncover genetic and environmental/ nutritional factors related to these chronic diseases, as well as the interactions between these two kind factors. The efforts should be in discovering the early stage molecular biomarkers for monitoring initiation and progress of major chronic diseases, which would then be the foundation to establish and continuously improve an evaluation system and corresponding diagnostic standards for chronic disorders. Researches would try to elucidate the relationship of malnutrition and nutritional imbalance between chronic diseases, and then develop new nutritional and therapeutics-based technologies to intervene initiation and progress of major chronic diseases. It is important to establish new diagnostic and evaluation technologies for the early stage diagnoses, especially which can finely differentiate health, sub-health and disease status, as well as significantly increasing continuous monitoring and diagnosis capability of human physiological and pathological status.

Medium-term goals (2021–2030): establish e-healthcare-managing system of the Chinese people based on information and internet technologies, and extend this kind of the health and chronic disease managing network to rural areas; develop personalized monitoring the early-stage of major chronic non-communicable disease; develop the nutritional and therapeutic intervention strategies for the early-stage prevention of the diseases to control and reduce incidence rate of major chronic diseases, which could be the foundation for screening out susceptible people in clinical and community healthcare practice. Through efficient nutritional intervention and therapeutics, researchers would put the development of chronic disease under control. Based on the technology of stem cell *in vitro* differentiation or tissue regenerative medicine, the pathological tissues or cells due to chronic diseases and degenerative diseases could be replaced or cured.

Long-term goals (2031–2050): control the rate and process of ageing; develop personalized prediction and intervention for the early stage of chronic diseases systematically; reduce incidence rate of chronic diseases and death/ disability rate resulted from chronic diseases nationwide significantly. Develop technological methodology for whole lifespan healthcare management. By then, Chinese healthcare model is shifted from therapeutic-centered healthcare to one focusing on healthcare management and prevention of chronic diseases.

6.2 Tasks

First and foremost, researchers should study genetic and environmental factors related to the major chronic diseases, including metabolic disorders, cancer, cardiovascular diseases and neural-degenerative diseases, and study the interactions between the two kind factors. Develop new animal chronic disease models that are closest to human life system; conduct researches on the mechanism of incidence and progress of the chronic diseases at the molecular, cellular, tissue- and individual-levels. Screen and validate genetic polymorphism and genetic markers closely related to nutrition in Chinese people, study the corresponding metabolic characteristics and mechanism of pathogenesis, and study the roles of these genes related to the incidence and progress of major chronic diseases.

Based on understanding of the mechanisms of the chronic diseases, researchers would screen for molecular biomarkers related to the incidence and progress of these chronic diseases, and then develop diagnostic technologies related to early stage of these diseases, and develop personalized monitoring approaches to differentiate the fine disease typing at the individual level. Develop new nutritional and drug intervention technologies targeting genetic and lifestyle problems unique to Chinese people. Another important task should be to conduct R&D on regenerative medicine based on stem cell *in vitro* differentiation or tissue replacement to cure damaged tissue resulted from chronic diseases.

Develop the evaluation scale system for health status of Chinese people, which addresses the genetic and lifestyle characteristics of Chinese people, and then develop related evaluation models. Develop key technologies for the personalized healthcare management system and establish database of related major chronic disease and physiological status biomarkers. Develop new health monitoring technologies based on biological chips, nanotechnology, micromechanics and information technology.

6.3 Technologies

6.3.1 Technology and Methodology Based on Systems Biology for Research on the Mechanisms of Chronic Non-communicable Diseases

Apply the research technologies of systems biology to elucidate genetic and environmental factors as well as their interactions related to chronic diseases in Chinese people, focus on the genetic and epigenetic variation of individuals particularly. Furthermore, researchers would study the structures and functions of the molecular networks related to the incidence and progress of the chronic diseases. Last but not the least, researchers would try to elucidate the different characteristics of the chronic diseases at various levels from tissue to individual, and integrate all information related to the diseases from the molecular mechanism, cellular behavior to pathologic changes.

6.3.2 Technology for Uncovering the Molecular Biomarkers in Monitoring Dynamic Changes of the Health Status and Incidence or Progress of the Chronic Diseases

Conduct the researches on the interactions between different diet, lifestyle and genetic variation as well as its impact on the chronic diseases. Uncover molecular biomarkers for the early-stage diagnosis with emphasis on genetic markers (genetic susceptibility or polymorphism) and phenotypic markers (proteins or metabolic small compounds) that involve in the incidence and progress of the major chronic diseases; build a biomarker-space by the combination of multiple molecular biomarkers from genetic markers to phenotypic markers to enable whole-course monitoring of the process of the major chronic diseases. Based on the understanding the interaction of genetic and environmental factors related to the progress of the chronic diseases, the monitoring techniques and standards for evaluation the process of the chronic diseases of Chinese people. Develop new personalized diagnostic technologies based on high-throughput genomics technology and other "omics" technology.

6.3.3 Technology and Methodology for Prevention and Intervention of the Chronic Diseases

The cellular and animal models would be applied on studying the molecular targets and mechanisms of the nutritional or drug intervention to the progress of the chronic diseases. On the other hand, Chinese cohort involving different stages of the progress of the chronic diseases should be constructed and subjected to the analysis by systems biology technology and methodology under the different nutritional or drug interventions. Based on these studies, the effective chronic-disease intervention methods would be established for Chinese people.

6.3.4 Evaluation Models and Methodology of the Healthcare Management Fitting to the Characteristics of Chinese People

Establish the standardized health evaluation system for monitoring the normal and sub-health status for Chinese people. Based on this system, the database including physiological, pathological indicators and population data would be constructed. Develop new technology that integrates epidemiology, biostatistics, computer science and information technology for the study of the standardized health evaluation system of Chinese people. Develop the information systems for dynamic healthcare management and for monitoring sub-health state. Based on these information systems, the researchers would develop the personalized healthcare management system for the specific needs of Chinese people and adapt to Chinese circumstances.

6.4 Roadmap

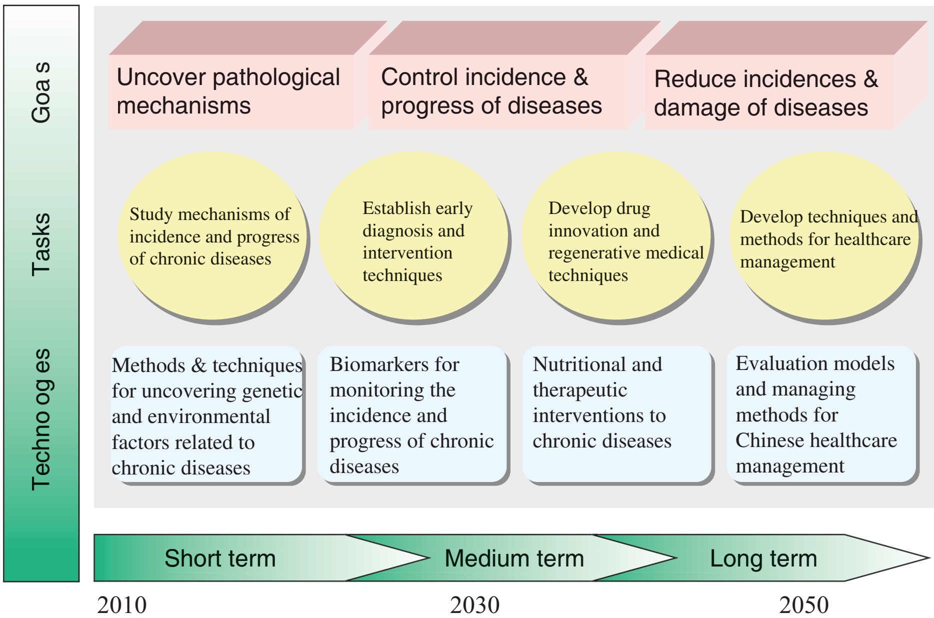

Fig. 6.1 S&T roadmap on chronic disease control and health management

7 Infectious Diseases Prevention and Control

China is a big country with huge regional differences in social economic development. The large population, high population density and mobility, as well as significant regional differences in life style make infectious diseases a major threat to China. With strong outburst and fast spread, infectious diseases are also more difficult to control in China. So China has to stick to a strategy which emphasizes both prevention and therapy in infectious disease control.

With open door policy, increasing commodities trading and people exchange with other countries, China will also face growing challenges of infectious diseases especially new and severe infectious diseases originated outside of China. An outburst of highly contagious flu or other fulminating infectious diseases will be a serious setback in China's strives to become a modern country.

7.1 Goals

Short-term goals (2010–2020): (1) establish a nation-wide surveillance and early warning forecast system for infectious diseases, which consists of State Centers for Disease Control and Prevention (CDC), hospitals and research institutions; (2) to establish a national high-level bio-safety laboratory network system and a national resource center and management system of bacteria (virus) strains; (3) develop rapid, sensitive, high-throughput detection technologies and methods for important infectious pathogens. In addition, China will also carry out basic and applied research for important infectious diseases in order to make breakthroughs in the research of etiology and pathogenesis, pathogens-host interaction, mechanism of cross-species spread, animal models, as well as the mechanism of drug-resistance of pathogenic microorganisms, vaccines and antiviral drugs. We would develop methodologies and technologies to reduce the infection rate and mortality of hepatitis, AIDS, and tuberculosis and establish public health emergency and anti-biothreats system with Chinese characteristics.

Medium-term goals (2021–2030): (1) improve the surveillance and early warning forecast system for infectious diseases and establish the high-level biosafety laboratory network and biosafety management system with regional nodes; (2) carry out a wide range of basic research for important infectious disease epidemiology and pathogenology systematically; (3) elucidate pathogen-host interaction and pathogenesis as well as the mechanism of cross-species spread, and (4) develop vaccines and antiviral drugs for infectious diseases including AIDS, tuberculosis, hepatitis C and in luenza successfully. Establish prevention, control and biosafety network for emerging and re-emerging infectious diseases.

Long-term goals (2031–2050): (1) establish a value chain linking basic research, vaccine development and clinical diagnosis; (2) elucidate the pathogenesis of important infectious disease pathogens, the mechanism of cross-species spread, the mechanism of virus genetic variation and individual differences in susceptibility and the mechanism of immune response and immune tolerance; (3) prevent the spread of HIV and other emerging infectious diseases effectively, reduce the morbidity and mortality of infectious diseases by developing individualized infectious disease prevention and control technology as well as wide range immunization among new-born and high-susceptibility population significantly; (4) establish prevention, control and biosafety network for emerging and re-emerging infectious diseases.

7.2 Tasks

In order to effectively control the outburst and wide-spread of important and server infectious diseases, reduce the morbidity and mortality of important infectious diseases as well as put the disease prevention-focused strategy into effect, China is determined to develop rapid, sensitive and high-throughput testing and monitoring techniques for infectious diseases and emerging infectious diseases; we will establish nation-wide surveillance and early warning system for infectious diseases and carry out molecular epidemiological study of important infectious diseases to determine the distribution and natural evolution of important pathogens as well as the relationship with environmental factors; in addition, China will also establish a biosafety laboratory network system with regional nodes and an independent biological resource center for infectious bacteria (virus) strains; we will emphasize the studies on etiology, animal models, dissemination and infection mechanism for key infectious diseases like hepatitis and AIDS, virus-host interaction as well as mechanism of cross-species spread of animal-derived pathogens and the drug-resistance mechanism of clinical microbial pathogens; China will also carry out of the studies on the endemic infectious diseases, including tuberculosis and schistosomiasis for the prevention and treatment, and the immune response mechanism of key and emerging infectious diseases. The country will launch research and development for innovative vaccine vector construction and new immunization strategy, set up the anti-viral drugs and vaccines screening and developing platforms for major pathogens, conduct research and development on small molecule compound drugs, peptide drugs, as well as therapeutic vaccines for viral and bacterial diseases; we would also establish a national antiviral drugs and vaccines reserve system for important infectious diseases.

7.3 Technologies

7.3.1 High-level Biosafety Laboratory System and Related Technologies

To establish a biosafety laboratory system with regional nodes and biosafety management system in accordance with international standards; to conduct the studies on development the technologies and equipments for personal protection sterilization, sealing and maintenance, as well as system integration of key equipments in an effort to improve the operation and maintenance of biosafety laboratory.

7.3.2 Efficient Screening System and Diagnostic Techniques

Set up a rapid, sensitive and high-throughput test and molecular diagnosis technology depend on nucleic acid or protein of pathogen and antibody; to develop new rapid detection method based on gene chip, protein chip and genomics technology; to establish cell lines, pathogen separation systems and micro-observation system which are helpful to pathogens isolation; to establish and continuously improve the databases for infectious pathogen genes, proteins, fingerprinting maps, pathogen epidemiology in order to provide reliable and comprehensive technical support to infectious disease screening, diagnosis, and pathogenic mechanism study.

7.3.3 Animal Models for Important Infectious Pathogens

Develop animal models for dengue virus, HIV, hepatitis C virus infection by improving existed animal model and exploring China's unique resources; to establish animal models for new emerging infectious diseases via new technologies such as stem cells, gene knockout and knock in for vaccines and drugs development.

7.3.4 Key Technology in the Studies on Infection Mechanism for Important Pathogens

To establish infectious cDNA clones, reverse genetic system, as well as the rapid, high titer pseudotyped virus packaging system for avian influenza virus, SARS corona virus, Japanese encephalitis virus and West Nile virus; to develop functional genomics and proteomics research technology for important pathogens such as Kaposi's sarcoma virus, cytomegalovirus and other large DNA viruses, as well as *Mycobacterium tuberculosis* and human - *Streptococcus suis.*

7.3.5 New Technologies for the Development of Drugs and Vaccines

Set up drug screening model and comprehensive drug library for important pathogens from computer molecular simulation, molecular identification to *in vivo* cell and animal infection; to develop new nucleoside and non-nucleoside drugs targeting reverse transcriptase of HIV and HBV, and innovative peptides or small molecule compounds against invasion and replication of the Japanese encephalitis virus, hepatitis C virus, in luenza virus, *etc*.; to develop genetically engineered vaccines against hand, foot and mouth disease virus (EV71, etc.) and rotaviruses from infants and children with diarrhea, subtype-specific or region-specific prevention or therapeutic vaccines against AIDS, vaccines for human against infectious diseases originated from animals such as avian flu virus and new anti-tuberculosis vaccines.

7.3.6 Clinical Patient Typing Technology Against Infectious Diseases

To establish database for infectious bacteria (virus) strains, clinical samples and information; to conduct clinical typing of patients suffering from infectious diseases via molecular biology technologies as well as meta analysis of pathogenesis mechanism of infectious diseases; to conduct clinical and animal model studies targeting di ferent types of patients in order to provide characteristic treatment for di ferent types of patients as well as provide clues for the development of new drugs and vaccines.

7.4 Roadmap

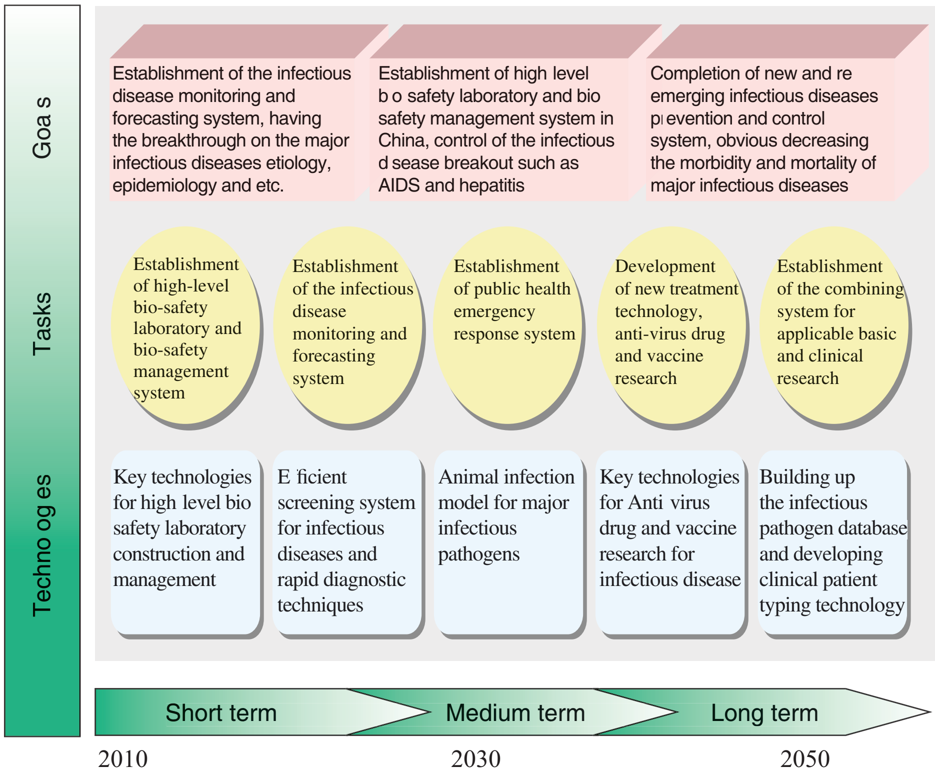

Fig. 7.1 S&T roadmap on prevention and treatment of infectious diseases and biosafety

8 Cognitive Neuroscience and Mental Health

Health has both physiological and psychological connotations today. WHO clearly states that "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity[9]." One important trend in disease profiling has been the rapid rise in the incidence of psychological and mental diseases in recent years. With the robust growth of IT and network technologies, more people now experience con lict between their virtual and real lives; the resulting psychological and mental health problems that may arise a tremendous challenge to future generations at present.

The discovery of the physical bases and mechanisms of the cognitive functions of the brain has long been an important scientific task and challenge, as the human race continues to try hard to understand itself. The most important task for future cognitive neural scientists and psychologists will be the investigation of cognitive functions, psychological activities and neural mechanisms from the gene-brain-behavior-cognitive point of view. Through research into the interaction between genetic and environmental factors and its role in the initiation and development of psychological and mental diseases, we can identify the potential causes of these diseases, establish *in vivo* molecular markers for monitoring them, develop integrated psychological and behavioral diagnostic technologies to implement their early diagnosis, and promote early interventions via drugs or non-drug therapeutics in our efforts to reduce their prevalence among the Chinese people.

8.1 Goals

Short-term goals (2010–2020): to elucidate the neural mechanisms for learning, memory and mood regulation, the processes of structural and functional changes during brain development and brain aging, and the relationships among brain elasticity and cognitive, behavioral and psychological activities; to conduct preliminary research into the basic rules that regulate human decision-making and its underlying neural mechanisms; to discover the preliminary cognitive neural mechanisms that are related to subjective happiness; to conduct preliminary research into the effects of virtual behavior on human cognition and behavior, as well as the mechanisms and causes of both drug and internet addiction, and identify and explore the predictors of and prevention methods for such types of addiction; to carry out preliminary research into the genetic and environmental factors that are related to cognitive and emotional disorders, as well as the neural mechanisms that underlie mild such disorders and their related social-behavioral characteristics, and indentify their corresponding risk and protective factors; to conduct preliminary research on the recovery processes of specific cognitive functions; finally, conduct preliminary research into the pathogenesis mechanisms of schizophrenia and depression.

Medium-term goals (2021–2030): to further elucidate the mechanisms of brain elasticity and its impact on human cognitive activities and social adaptability; to identify the mechanisms that underlie such cognitive functions as human decision-making at the molecular, neural circuit and individual levels; to elucidate the impact of emotion, mood and culture on economic and social decision-making and its underlying neuroeconomic mechanisms; to establish a cognitive and behavioral methodology that can effectively maintain and enhance subjective happiness among the Chinese population; to establish and develop a dynamic, individualized drug and Internet addiction monitoring system, as well as such therapeutics as cognitive-behavioral and emotional regulation therapy; to enhance the psychological health of the Chinese population via new behavioral education models and psychological care; to further elucidate the biological and neural mechanisms that underlie emotional or mood disorders; finally, determine individualized diagnosis and evaluation standards for major mental diseases, identify the critical points between normal aging and mild cognitive disorders, and conduct cognitive-behavioral interventions that target cognitive defects among such disorders.

Long-term goals (2031–2050): to elucidate the brain mechanisms of the human consciousness and promote the application of artificial intelligence and calculation intelligence; to elucidate the biological mechanisms that underlie human decision-making and develop techniques to assist such decision-making; to develop targeted technologies that enhance the subjective happiness of different groups of people; to elucidate the molecular mechanisms of the protracted and intractable nature of memory in addiction and significantly reduce the damage caused by drug and internet addiction; to establish a preliminary predictive model for mental disorders and abnormal decision-making behavior and provide pertinent intervention and therapeutic planning; to establish a cognitive-neural-psychological recovery system for cerebral organic disease or trauma-induced changes based on brain elasticity research; to establish social and healthcare systems that readily address the cognitive problems that arise in an aging society; ̀inally, establish an indicator system for the screening of and intervention in mental disorders.

8.2 Tasks

To discover the neurological bases of cognitive, behavioral, psychological and mental activities; to elucidate the relationships among brain elasticity and learning, memory, attention, and emotion; to elucidate the cognitive processes and neural mechanisms of learning and memory, as well as the biological bases and psychological mechanisms that underlie the subjective happiness, human decision-making, and consciousness generation and processing; to discover the brain functional network status and its functional model, as well as the neural mechanisms that are related to psychological health; to reveal the functioning mechanisms of genetic and environmental factors and their impact on cognitive, psychological and mental activities; and to develop brain elasticity technologies that promote mental and psychological well-being.

In addition, future research should aim to reveal the initiation mechanisms of cognitive, psychological and mental disorders; screen for the *in vivo* molecular markers of the initiation and development of cognitive disorders and establish predictors and systems; develop technologies that integrate the biomarkers of and behavioral examination for mental diseases; establish individualized diagnostic standards that are based on an evaluation of gene and cognitive functions; establish standards for the early-stage diagnosis and typing of mental diseases; and develop prevention methods for cognitive, psychological and mental disorders, as well as effective intervention therapies.

8.3 Technologies

8.3.1 *In vivo* Neuron Molecular Markers and Brain Function Imaging Technology

The key technologies in this arena involve the development of *in vivo* neuron molecular markers that target living tissues and cell-specific molecular pathways; the development of highly sensitive and specific molecular probes that aim to increase probing capabilities by a magnitude of 1 to 2; and the implementation of the *in vivo* imaging of specific molecular events and cellular communication.

8.3.2 Brain Structure and Function Database for the Chinese Population

Reaching the ultimate goal of establishing a brain structure and function database for the Chinese people requires the development, via molecular imaging, of a structure and function imaging map of the brain cortex, including the cortex complex, which plays a key role in cognitive functioning; the development of a new technology for the study of the localized functioning and interaction, such as dynamic and static functioning and effective connections, between groups of neurons or between neurons from different locales of the brain; and the development of a new technology that will allow the standardization of multi-site, multi-level data.

8.3.3 Basic Psychological Characteristics Database for the Chinese Population

It is necessary to develop a scaling methodology for basic cognitive functions, as well as a database of these functions and disorders among the Chinese people; to establish longitudinal cognition-, psychology-, behavior- and physiology-tracing databases for different age groups in China; and to establish a behavior-, brain-gene or other biomarker-based early-stage dementia warning system specifically for the Chinese elder, dementia intervention programs that are based on basic cognitive capability training, and a prevention and intervention network that covers grassroots communities with regard to psychological, cognitive and mental disorders.

8.3.4 Individualized Diagnosis Model for Cognitive, Psychological and Mental Disorders

This goal requires the development of an examination technique based on personalized genomics or metabolomics, as well as physiological and biochemical function and molecular imaging to detect changes in brain structures and functions; the development of cognitive, behavioral and psychological methods to evaluate individual cognitive, psychological and mental status; and the use of systematic biology and bio-informatics analysis systems to evaluate the risks posed by mental disorders and facilitate early-stage diagnosis and disease-typing.

8.3.5 Integrated Experimentation Techniques

The development of integrated experimentation techniques for live-tissue specimens and conscious and free-moving animals is necessary. Such techniques could simultaneously make use of physiological, biochemical, pharmacological and brain function imaging methods to record and analyze various interrelated data. Also required is the development of arti icial intelligence technology that simulates the human brain, human-computer interaction technology, brain-computer interface technology, cognitive behavioral examination technology for free-moving conditions, and affective robot technology.

8.3.6 Brain Elasticity Regulation Technology

Future research should establish elasticity regulation technologies based on cognition, psychology and behavior, technologies that may utilize simple and pertinent cognitive, psychological or behavioral methods, accompanied by biological feedback technologies based on brain-functioning parameters, to readily inform participants of their brain-functioning status. In this way, participants can learn how to make step-by-step adjustments and gradually improve their self-awareness and self-regulation capabilities. This will allow them to become aware of their psychological and brain-functioning status, and to adjust their psychological activities accordingly so that they can return to a healthy status.

8.3.7 Virtual Reality Technology

The development of virtual reality experimentation technologies for psychological health research and behavioral observations is a must. A virtual reality experimentation system could provide photographic multi-modal information that replicates to a high degree what takes place in the natural environment. Such a system could also enable researchers to systematically control and manipulate the interaction between operators and the environment, thus providing information that could subsequently be used in research on anxiety disorders and the mechanisms of post-traumatic stress disorder, to conduct cognitive evaluations of brain damage and practice recovery training.

8.4 Roadmap

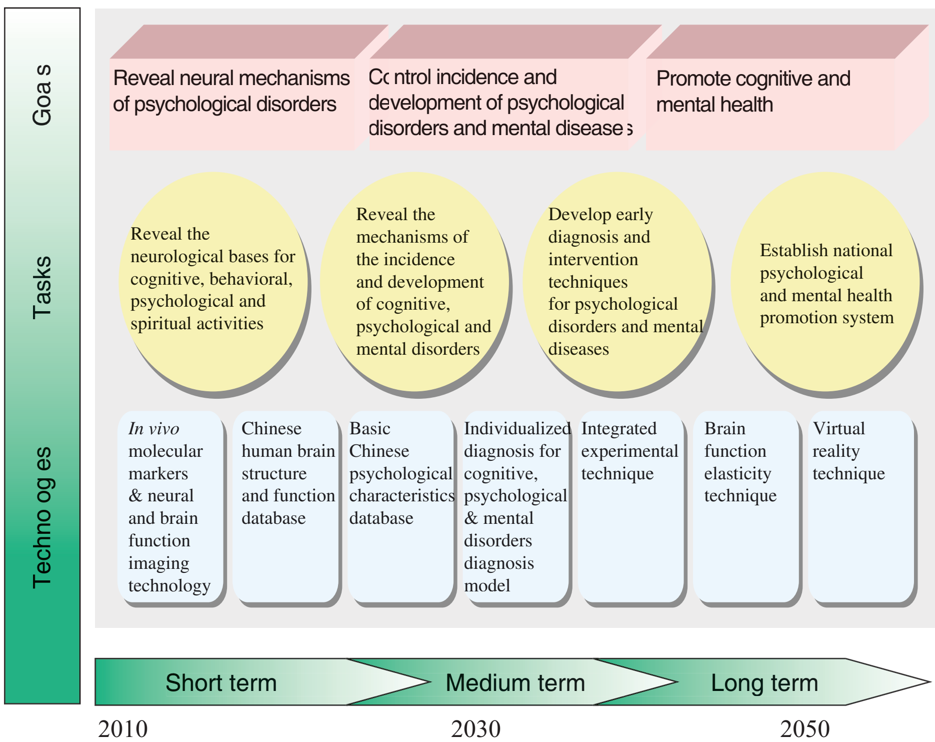

Fig. 8.1 S&T roadmap on cognitive neuroscience and psychological and mental health

9 Innovative Drugs and Biomedical Engineering

In the recent 20 years, rapid improvement has taken place in the research and development (R&D) of innovative drugs, which mostly manifested in the following two aspects. On one hand, with the advancement of genomics, proteomics, systems biology, stem cell research and other modern biotechnologies, more and more details have been revealed relative to mechanisms of disease etiology which further facilitates the discovery and validation of novel targets and changes the thought and the model of developing new drug ; on the other hand, burgeoning sciences such as structural biology, computer and information technologies are emerged in early stage of drug discovery and research deeply more and more, while continuous cross-fostering with chemistry and physics brings about dramatic changes in the landscape of innovative drug development.

China is committed to mobilize its resources to speed up the pace of drug discovery and technology innovation aiming at joining the global competition. While small molecule compounds will always be of value and remain a focal point of our efforts, we would also fully utilize the strength of Traditional Chinese Medicine (TCM) and make biotechnology drug a priority in the rapid growth of Chinese pharmaceutical industry. R&D would be closely linked with commercialization of modern biotechnology drugs, and new therapeutics or intervention methods shall be developed by means of new drug targets .

Biomedical engineering integrates the theories and methods of engineering, biology and medical science thereby providing a comprehensive solution for the prevention, diagnosis, treatment and cure of various diseases. Currently, biomedical engineering covers the fields of biomechanics, biomaterials, artificial organs, modeling and controlling of biosystems, signal detection and biosensor, the methods of biomedical signal processing, medical imaging and image processing, therapy and rehabilitation engineering, minimally invasive surgery, tissue engineering, geriatrics, clinical information technology, *etc*. Due to significant contributions of biomedical engineering to the healthcare industry, we would make its development a long strategic goal in the public health of China .

9.1 Goals

Short-term goals (2010–2020): to establish an integrated systematic, fully functional national drug discovery and development system with key technology platforms in line with (or better than) international norms; to develop several innovative drugs with international mainstream market prospect; to make China's pharmaceutical industry among the world's top 5; to set up and continuously improve efficacy evaluation and quality control system as well as safety assessment and re-assessment standards for TCM; to construct integrated and large-scale genetic engineering and protein engineering technology platforms thereby major efforts could be directed towards the development of various biological drugs such as humanized antibodies; to develop novel diagnostics and therapeutics for major diseases as well as new biochemical analysis and clinical testing methodology and equipment; to study new functional biomaterials, artificial organs and human-machine interface, medical imaging system and new physical therapy equipment.

Medium-term goals (2021–2030): our objective is that China's innovative capability in drug development will reach the level of developed countries in this time frame. The plan includes: to acquire a series of key development and commercialization technologies for small molecule and biological drug innovation; to launch a number of new chemical entities with international impact and to grow China's indigenous pharmaceutical industry to become the top three in the world; to apply contemporary technologies for elucidation of the material basis of TCM actions and underlying mechanisms in disease intervention, thereby developing new therapeutics from TCM including entrance to the mainstream international market; to make breakthrough advancement in key biomedical engineering technologies and to produce reliable, convenient and advanced medical equipment; to facilitate the transition of China's healthcare system from hospital based care to a combination of prevention, exercise and personal care.

Long-term goals (2031–2050): China will become one of the global leaders in pharmaceuticals and biomedical engineering; to establish a drug innovation system with Chinese characteristics capable of delivering original innovation continuously; to play an important role in devising drug evaluation standards; to significantly enhance human's the ability of living in a healthy state and to meet the public demand for better healthcare; to construct a comprehensive biomedical engineering value chain from R&D to commercialization, which would become one of the pillar industries in bioeconomy and healthcare.

9.2 Tasks

Conducting innovative drug research based on bionetwork regulation and system biology for complex diseases with cross technologies of multidisciplinary nature; utilizing knowledge on genetic diversity and gene polymorphism to develop individualized diagnosis and therapeutics; carrying out basic and applied research on drug delivery system, insipient, new formulation with specific function and “intelligent” drugs which are both effective and safe; significantly improving innovation capability in biotechnology drug development and launching a series of protein, nucleotide based drugs; study new biological and small molecule induced stem cell differentiation with an aim of discovering new therapeutic applications; developing key technologies in genetic engineering, cell engineering and bioreactors; striding great progresses in biotechnology innovation to meet major medical demand and to speed up related commercialization process.

Expedite integrated innovation. To fully leverage China’s strength of a strong government, integrated technology platforms concerning drug discovery, preclinical and clinical research, as well as commercialization, must be established and continuously improved. This includes technology transfer platforms of bioengineering products. While encouraging universities, research institutions and industrial sectors to work together on drug innovation and bioengineering, the government would also fully leverage integrated innovative capabilities of various technology development centers and incubators thereby radiating specialized technology platforms built by enterprises and form the core of a national drug and bioengineering innovation system. We would strive to make the quality control standards of such technology platforms in line with that of international standard in our effort to target important overseas markets.

We would also fully leverage the strength of TCM and the knowledge accumulated over thousands of years of its clinical practices; we would utilize the ever advancing life science, mathematics, physics, chemistry, and information technology to develop new techniques and methods to reveal active components and underlying mechanisms of TCM action as well as to discover new medical resources and novel therapeutics based on the aforementioned advancements.

We would push forward the integration of discovery, development and commercialization processes while improving the innovative capability of industry and make it as a major player in China’s pharmaceutical business, where domestic drug and biomedical engineering innovation system will be driven by market demand. This strategy is consistent with China’s effort in improving industrial innovation capability and commitment to better regulate venture capital investment and to encourage technology transfer, with an ultimate goal of maximizing industrial strength.

9.3 Technologies

9.3.1 Drug Discovery Technology

We intend to acquire certain key technologies targeting bottlenecks in global drug discovery. Focuses will be directed towards improvements in essential technology platforms such as drug screening, compound library, and molecular design with special emphasis given to target discovery and validation, as well as high throughput screening technologies. We would employ highly efficient synthesis technology to construct drug-like compound library; apply transgenetic techniques to pharmacology, bioavailability, metabolism and safety evaluation; establish early stage drug evaluation system at molecular, cellular, organ (tissue) and whole animal level; develop new theory and methodology in lead discovery and optimization to increase the success rate of innovative drug research.

9.3.2 Innovation Technology Based on Network Pharmacology

As single target high-throughput screening technology would not meet the demands of drug discovery for complicated diseases, we need to develop systems biology and network pharmacology based new drug discovery method via integration and development of bioinformatics, cheminformatics and pharmainformatics. Based on systems biology research of pathogenesis of multi-gene related diseases such as cancer and metabolic disorders, we plan to develop drug screening technology targeting disease related genes and their regulation network, suitable pharmacological models multi-target assessment techniques of synergistic effects will also be studied.

9.3.3 Technology in Personalized Drug Discovery

We would conduct research on the differences in efficacies and adverse reactions among patients with different genetic backgrounds and use molecular biology, genomics and proteomics to develop various personalized diagnostic chips and therapeutic tools to increase drug efficacy and safety. We would also study the genetic polymorphism of proteins related to drug metabolism among different races and individuals as well as its impact on drug reaction. Based on the results of these studies, we would develop agents and dosage forms corresponding to the genotype of patients, which would subsequently increase drug efficacy and reduce adverse reaction among various individuals or races.

9.3.4 Drug Development Technology Based on Stem-cell

We shall establish new screening assays or technologies based on advancements in stem cell research. This is particularly useful for complex diseases such as cancer, genetic disorders, tissue degenerative and autoimmune diseases, etc. Together with the help of traditional drug discovery strategy, we plan to make a progress in innovative drug development through discovery of small molecules that can induce differentiation of stem cells or the generation of iPS cells.

9.3.5 Drug Safety Technology

With the focus on improving safety and drugability, we would develop and improve new theory, technology and methodology of drug safety forecasting and evaluation as well as establish new toxicity prediction models with efficacy and accuracy higher than that currently in use. We intend to set up animal models that can more accurately simulate toxicity in humans and improve our ability to discover at early stage any adverse drug reaction as well as its mechanism of action.

9.3.6 Technology in Drug Release System and Formulation

We intend to establish advanced "intelligent" drug release and formulation systems, and to conduct research and development of novel formulation incipient. We will attempt at realizing real-time, dynamic, and minimally invasive *in vivo* monitoring of drug and its carrier at both tissue and cell levels. This would involve the establishment and improvement of both *in vivo* and *in vitro* evaluation and mathematical modeling systems of new formulations, reinforcement of R&D of new incipient and materials, development of formulation and delivery vehicle based on molecular mechanism of drug transportation, including targeted, long-lasting, or fast-acting drug delivery systems, as well as finely controlled release system which would enable targeted, quantitative, and real-time release of drugs *in vivo*. Drug-specific formulations and technologies that can facilitate solubility, bioavailability and transportation while reducing adverse effects will also be sought. Furthermore, studies on biocompatible material, controlled micro delivery system, advanced manufacturing technology and associated device and formulations, etc. will also be performed.

9.3.7 Technology in TCM research

We are committed to perform basic research and key technology platform construction on TCM, this includes setting up and continuously improving TCM prescription database, natural product database, Chinese medicinal material database, as well as database for medicinal material and natural products reference standards. With the help of systems biology, chemistry, mathematics, physics and information technology, further elucidation of active TCM components and their mechanisms of action would be possible that will lead to the development of new TCM preparations. It is essential to study new techniques or methods and apply them to the development of innovative TCM that fully address its multi-component and multi-target characteristics, in conjunction with the establishment and constant improvement of clinical efficacy evaluation system that confers the uniqueness of TCM. Ultimately, we shall utilize modern technologies to develop TCM products with global acceptance and to enforce quality control standards that are in line with the international standard.

9.3.8 Large-scale Biological Manufacturing Technology

This will involve the establishment of large-scale high-throughput gene screening and protein expression technology platforms to obtain high-expression engineering bacterial strains or engineering cell lines, to produce engineering bacterial strains or engineering cell lines on a large-scale, to develop new protein purification process/technology and bioreactors for large-scale manufacturing of enzymes, biodrugs, antibodies as well as useful metabolites. Obviously, this would require close interdisciplinary communications between scientists in systems biology, cell engineering and tissue engineering, and emphasis will be given continuously to improve pilot testing incubation techniques.

9.3.9 Technology in Biomaterials

We would develop key elements and technologies related to biosensor (including both signal detection and amplification) such as biomolecule interaction based high-sensitive biosensor, interchange and amplification technology of bio-signals and opto-electronic signals. New biomaterials and tissue engineering materials, such as antibiotic peptides, internal stent with sustainable anti-infection function, biocoagulant with specific peptide sequence, neuro-regenerative induction materials with orientation function, etc. are presently targeted. Clearly, biomaterial self-assembly and bio-mechanical interface technologies should also be sought to produce bio-mechanical and pure biocompatible arti ìcial organs.

9.3.10 Biomedical Engineering Technology

We intend to study *in vivo* transmission and distribution of light, sound, electro-magnetic and nuclear radiation, with an aim to develop more sensitive and reliable early stage diagnosis. This could include some deep, high-resolution and minimally invasive diagnostic tools and imaging systems, such as non-imaging graphic enhancer type cardiovascular, cerebrovascular image and diagnostic systems based on non-imaging enhancer, rotational echo double resonance-magnetic resonance imaging(REDOR-MRI), etc. On the other hand, small volume, micro dosage, intelligent and automatic electronic devices, biochemical instruments, various signal processing and analytical technologies, and new therapeutic devices based on X-ray, γ-ray, radioactivity, ultrasonic techniques should be carefully evaluated.

9.3.11 Technology in Resource Integration

Our efforts will be directed towards resource integration and expansion by means of improving various resource databases related to innovative drug research such as target database, compound library, microorganisms library, animal and plant sample library, etc. Special attention will be paid to develop technologies related to digitalized management of resources and data/

information acquisition, storage, retrieval, analyses and utilization.

9.4 Roadmap

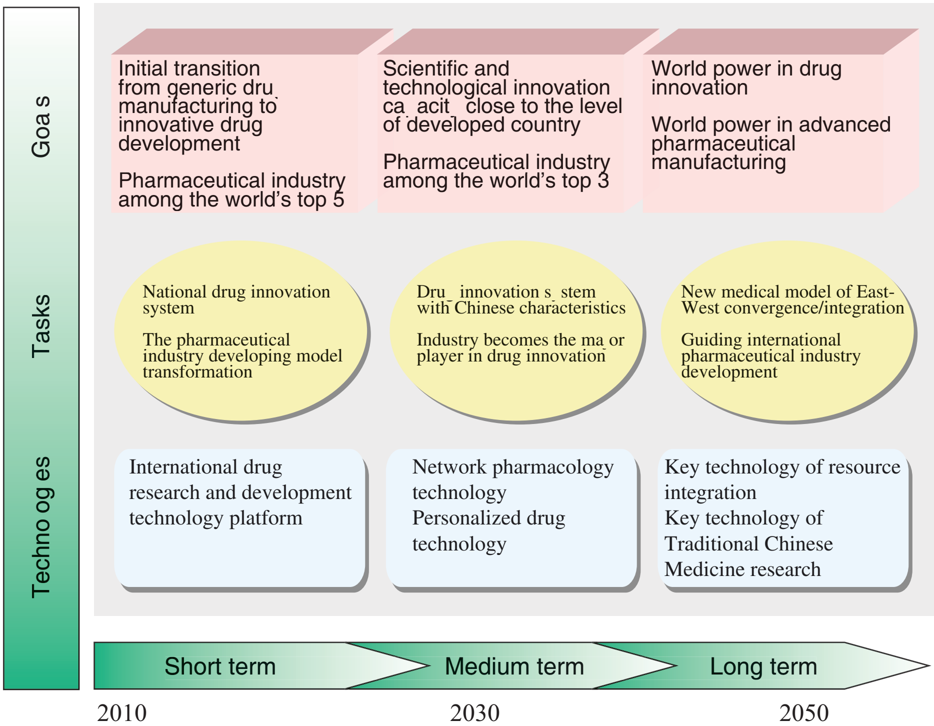

Fig. 9.1 S&T roadmap on drug innovation

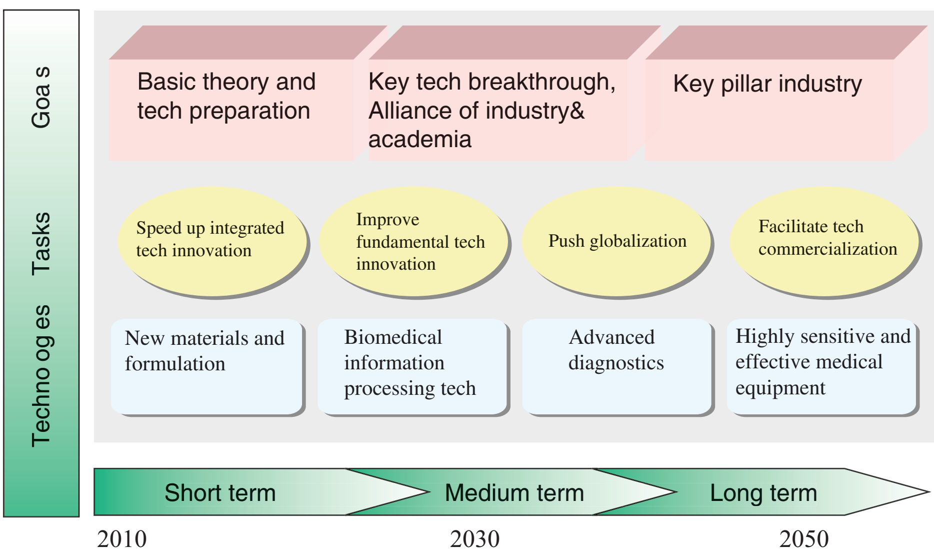

Fig. 9.2 S&T roadmap on biomedical engineering

10 Regenerative Medicine

Early civilizations learned to treat illnesses through herbal remedies, which evolved into drug therapy that can be considered the ̀irst revolution of human disease therapy. With increasing understanding of the human body, surgical procedures were developed to remove or correct diseased tissues or organs, so that surgery may be considered as the second revolution in medical history. The advance in stem cell biology and tissue engineering is heralding a new era of disease therapy called regenerative medicine. By repairing, replacing and regenerating damaged, diseased or aged tissues and organs, this emerging field is cross–and multi–disciplinary, thus, may bring in the third revolution in human therapy after drug and surgery.

Stem cells, as both the therapeutic agents and research focus of regenerative medicine, bridge both the basic sciences and clinical medicine in multiple fields. On the basic side, stem cells serve as an ideal model to explore many important biological questions such as the cellular and molecular mechanism of many pathophysiological processes, cell growth and differentiation, and organogenesis. Clinically, stem cell therapy can be applied to virtually all human diseases, especially those with unmet medical needs.

The key question and approach of regenerative medicine is to development of novel stem cell technologies for disease therapy and generate or regenerate human tissues and organs *in vitro* or *in vivo* for transplantation. Stem cell biology and Regenerative Medicine represent the current frontier of modern life science, will become the mainstream of scientific research. The convergence of regenerative medicine and modern biomedical technologies may facilitate the realization of age old dreams for the mankind to repair and regenerate human tissues and organs, prolong life expectancy, and improve quality of life.

10.1 Goals

Short-term goals (2010–2020): Make out a comprehensive national program for stem cell research by focusing on key scientific questions of the field, including areas such as the isolation, storage, characterization and evaluation of various embryonic stem cell and adult stem. This program will enhance the overall capability of China's stem cell research, develop a solid infrastructure for regenerative biology and medicine for potential breakthroughs in selected therapeutic areas. For basic research, this program will focus on dissecting the molecular mechanisms associated with self-renewal, differentiation and reprogramming, the three key questions of stem cell research. The outcome of the basic research will lead to improvements in large-scale expansion of stem cell culture, specific differentiation of pluripotent stem cells and transplantation of stem cells without immune rejection. In the applied and technical side, the program aims to de ine cell lineages of the human body using cell surface marker, gene profiling. One of the goals is to distinguish and characterize the 200 or so cell types which can serve as references for cells that can be used for disease therapy in the future.

Medium-term goals (2021–2030): (1) establish a stem cell based research platform in regenerative medicine, deploy regenerative medicine in the clinic for select diseases, and improve the overall research capability in clinical applications of regenerative medicine; (2) investigate the relationship among cell, tissue and organ, delineate the mechanism governing the organogenesis and tissue formation from stem cells, explore the feasibility of tissue and organ regeneration *in vitro*; (3) understand the molecular logic between self renewal, differentiation and reprogramming through chemical biology, develop a series of tools that can control stem cell fate, and establish a comprehensive knowledge base for stem cell sciences; (4) once the basic questions concerning tissue stem cells are well understood, establish standardized methods to derive, store and utilize pluripotent stem cells, efficient systems to generate tissue specific cell types from pluripotent stem cells, and capabilities to derive speci ic cell types for various tissues and organs from stem cells; improve and perfect stem cell transplantation technologies; develop methods to correct genetic mutations *in vitro* based on embryonic stem cell technology and realize the goal of stem cell therapy for genetic diseases; (5) achieve original breakthroughs in developing technologies to evaluate both safety and e ficacy of stem cell therapy.

Long-term goals (2031–2050): (1) make breakthroughs in tissue and organ regeneration technologies, apply these advances in the clinic to achieve regenerative therapy, such that China becomes a leading country in the field of regenerative medicine; (2) understand the molecular mechanisms of stem cell proliferation, differentiation, tissue and organ formation by investigating the properties of embryonic and adult stem cells and ways to isolate, analyze and characterize these stem cells; (3) establish a comprehensive program to differentiate pluripotent stem cells into all the cell types of the human body, automate and standardize the culture, storage, differentiation and characterization of stem cells; (4) develop solutions to aging related degenerative diseases through stem cell based regenerative medicine; (5) develop artificial organs from biomaterials and animal models to meet the shortage of organs or tissues for transplantation, master the techniques of tissue or organ regeneration and replacement to facilitate therapeutic breakthroughs in regenerative medicine for major diseases in both China and the world.

10.2 Tasks

The main mission of regenerative medicine is, through research on questions in stem cell biology, to develop novel stem cell technologies, understand the basics of tissue and organ formation, create platforms to generate tissue and organs *in vitro* and *in vivo*, and develop therapies for human diseases through comprehensive research in basic, applied and clinic aspects of regenerative medicine. To achieve this mission, it is imperative to build a strong infrastructure for stem cell research, form strong alliances between basic research institutions and medical organizations, establish a unique research enterprise in China by incorporating various medical institutions, create cross discipline research centers of regenerative medicine, and improve the overall research capability of regenerative medicine in China.

Specific research areas include: Establish (1) a nation wide stem cell research network to systematically investigate the mechanisms associated pluripotency, differentiation and reprogramming; (2) a fully integrated system that can implement stem cell therapy and other regenerative therapies such as tissue or organ regeneration; (3) a large scale stem cell bank to standardize stem cell storage, culture and related services; (4) a platform technology for tissue or organ generations in animal models suitable for xenotransplantation; (5) induced pluripotent stem cell technology and its applications; (6) a differentiation platform to generate all cell types in the human body from iPS cells; (7) a program to use patient specific iPS cells to treat organ failure or genetic diseases; (8) a single cell research capability including the isolation, expansion, storage and characterization of single cells; (9) cloning technology platforms by focusing on large animal cloning and transgenics; (10) platform technology for tissue or organ regeneration *in vivo* and *in vitro* using advanced biomaterials and unique large animal models or carriers.

10.3 Technologies

10.3.1 Somatic Cell Reprogramming Technology

Based on iPS research, it is possible to discover novel compounds or design novel compounds that can substitute the 4 transcription factors that are required to start the reprogramming process. Fully chemically induced pluripotent stem cells may be established and they will be safer for human disease therapy. These patient specific pluripotent stem cells can be then differentiated into cell types suitable for the generation of tissues or organs for transplantation. On the other hand, the chemical iPS cell lines can be produced in a GMP facility for clinical application. By combining these clinical grade cells with biomaterials and bioengineering tools such as scaffolds and chemical inducers, it is also feasible to assemble tissues or organs *in vitro*. By establishing large animal models, these iPS based tissues or organs can be tested for preclinical efficacy and safety prior to clinical testings.

An iPS cell bank can be established gradually to include cells from both healthy and patients from different geographic and ethnical backgrounds. It is critical that China should establish standards for iPS based therapies including efficacy, safety and post-operational monitoring. For example, large animal models should be established for hematopoietic stem cell transplantation research to investigate the immune compatibility, homing, implantation kinetics, cytokine responses and radiosensitivity for transplanted stem cells. Nonhuman primate models will be critical for the evaluation of iPS derived hematopoietic stem cell therapy, especially the development of clinical procedures, cytokine boosts and the reconstitution of the entire hematopoietic system in preclinical studies.

An automated platform for single cell handling should be established. This system should include methods to culture and differentiate single cells, improve induced differentiation of stem cells by combining nanotechnologies, optically controlled handlers, and perform high throughput screening and highly sensitive assays using single cell technology.

10.3.2 Animal Somatic Cell Cloning Technology

Cloning technology is still at an early stage of development and remains poorly understood in theory and inefficient in practice. It is essential to formulate a strategy focusing on several key scientific questions related to cloning, such as DNA methylation, genetic imprinting, cell cycle, nuclear-cytoplasmic interaction, and the reprogramming of donor nucleus by cytoplasma. Nevertheless, there is little doubt that somatic cell cloning will play an important role in regenerative medicine due to its unique technical advantages. For example, cloning technology can generate unique animal models and expand a specific colony of animals. It is feasible to produce biomedical animal models from cloned sheep, cow and pigs and some of these animals may provide engineered tissues and organs for transplantations. It is anticipated that the successful elucidation of epigenetic mechanism and reprogramming pathways may bring out major breakthroughs in mammalian regenerative biology. Should xenocloning, i.e., the use of eggs from another closely related species for cloning, be successful, or artificial or engineered ovary or oocytes, it may be possible to save endangered species such as the panda through cloning.

10.3.3 Embryonic Stem Cell Technology

The main focus to develop embryonic stem cell technology will be the following: (1) methods to acquire and culture embryonic stem cells safely and efficiently; (2) establishing standards to characterize, culture and store embryonic stem cells and trying to automate these procedures; (3) differentiation of embryonic stem cell towards a particular lineage or an organ, automation of cell separation and characterization, and assembly of organ-like structures using tissue engineering materials; (4) transplantation of embryonic stem cells or cells derived from them in the clinic and the development of techniques to evaluate the efficacy and safety of stem cell transplantation.

10.3.4 Adult Stem Cell Technology

Adult stem cells are cells in tissues with finite differentiation capabilities, such as hematopoietic stem cells and bone marrow mesenchymal cells. Adult stem cells can be used to treat diseases and the following technologies are needed: (1) adult stem cell harvesting: automated stem cell sorting system to separate and purify adult stem cells from different organs; (2) adult stem cell amplification and identification. use non-animal-derived culture system with defined chemical compositions to culture adult stem cells, and implement automation of the whole amplification-identification process; (3) adult stem cell transplantation and application: acquire new technology to reduce or eliminate immunogenicity of adult stem cells and achieve adult stem cell allograft transplantation without rejection, and evaluate the efficacy and safety.

10.3.5 Tissue Engineering Technology

Advances in the stem cell technology may bring breakthroughs in tissue engineering. First, as seed cells, stem cells provide the initial cell will bring important breakthroughs for tissue engineering. First, as seeds, stem cells serve as starting materials for tissue formation *in vitro*. Embryonic stem cells, pluripotent stem cells and various tissue stem cells are the major sources of seed cells for tissue engineering. Second, the extracellular matrix plays vital role in supporting tissue morphogenesis, thus, must be mimicked functionally to provide the necessary scaffolds for tissue regeneration. Lastly, a culture system should be established to accommodate the stem cells and scaffolds for the formation of various functional tissues *in vitro*, such as skin, tendon, muscle, and neurons. Thus, the successful integration of stem cells and ECM, *in vitro* generation of functional tissues that resemble those in the human body, and overcoming immune rejection for transplantation of these biomaterials and tissues are the key milestones for regenerative medicine.

10.3.6 Organogenesis Technology

Organ transplantation is the most effective treatment for certain human diseases associated with tissue or organ damages. Artificial heart or kidney or similarly engineered devices may work to alleviate a narrow spectrum of organ dysfunctions. So far, it has been difficult to substitute more complex organs with similar devices. As organogenesis begins to be well understood at the cellular and molecular levels and advances in materials sciences and bioengineering, biologically constructed artificial organs may become possible. Currently, very little is known about organ development and regeneration. For organs with regenerative potentials such as liver, their stem cells have not been isolated and characterized properly. On one hand, only very limited number of cell types such as neuron can be generated successfully from pluripotent embryonic stem cells. Therefore, the key to develop artificial bio-organs is to investigate and understand the molecular and cellular mechanisms governing tissue and organ formation during development. *In vitro*, advanced materials, especially those from nanotechnology may allow the engineering of three dimensional scaffolds mimicking both the shape and size of a particular organ such that stem cells or iPS cells can be implanted for *in vitro* organogenesis. On one hand, large animals such as pig can be engineered genetically to be immune deficient, thus, may serve as donors or carriers for organogenesis *in vivo*. It has been recognized that organ regeneration is one of the major challenges in regenerative medicine. This may be accomplished in two steps. First, one may take advantage of animal models to humanize a given organ such as kidney in large animals such as pig mentioned above for transplantation into human recipient pending complex evaluation of safety and efficacy. Secondly, based what can be learned in humanizing organs in animal carriers, attempts can be made to construct similar tissue or organs *in vitro* using advanced stem cell technology and materials technology. So it is important to identify suitable animal carriers that resemble human development and physiology, investigate the ability of human stem cells to colonize the target organ or tissue and explore the feasibility of organ formation based on human stem cells. One may also model the *in vivo* environment for organogenesis in culture, allow stem cells to interact with the proper scaffolds to support organogenesis, which may eventually lead to organ production on a large scale.

10.3.7 Evaluation Techniques for Safety and Efficacy of Transplantation

Safety and efficacy are the two key determinants for successful transplantation of stem cell and organ. Compared to drug therapy, stem cell and organ transplantation are much riskier and more difficult to perform. Therefore, an evaluation platform must be established to assess safety and efficacy for various stem cell and organ transplantations.

Quality control system must be established based on advances in stem cell biology and related technologies. The key features may include systematic analysis of stem cell properties such as cell surface markers, gene expression profiles, standardized differentiation potentials with both quantitative and qualitative criteria, and contamination of animal or microbial products in the culture systems.

Similar quality control system should be established for tissue and organ based therapy. Specific criteria may be determined according the properties of each tissue or organ. For example, each tissue or organ possesses unique physiological characteristic, which should be the basis for establishing the appropriate quality control standards. The physiological as well as biochemical standards may be used for surveillance purpose. Finally, it is critical to monitor in real time the transplantation process such that early efficacy can be assessed according to the properties of the transplanted cells, tissue or organs.

10.4 Roadmap

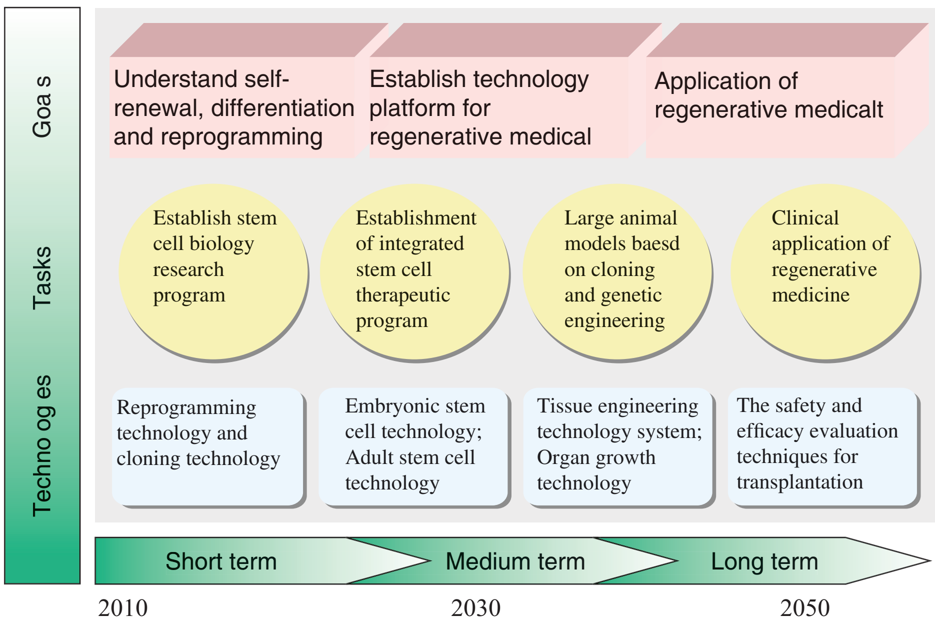

Fig. 10.1 S&T roadmap on regenerative medicine

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