Introduction to Results of Life Sciences from SJ-10 Recoverable Satellite

Enkui Duan and Mian Long

Abstract Space life science and biotechnology is to conduct the biological and biotechnological experiments of various species in space by utilizing the space hardware in the space vehicle, in which the effect of microgravity and space radiation on biological activities is a crucial issue in this field. The experiments conducted in a Shijian-10 (shortly, SJ-10) recoverable satellite mission are segregated into two groups. One is physical science under microgravity, consisting of eleven experiments. Another is space life science, being composed of ten experiments. In space life science, three categories are defined as radiation biology (Chaps. 3, 4 and 5), gravitational biology (Chaps. 6, 7 and 8), and biotechnology (Chaps. 9, 10, 11 and 12). Meanwhile, the system design and flight results of the SJ-10 satellite (Chap. 2) and the related techniques, space hardware and ground-based devices are described (Chaps. 13 and 14). In this chapter, the summaries of this book including the introduction to SJ-10 recoverable satellite and ten space life science projects as well as the scientific issues and Chinese scientific advances in the field of radiation biology, gravitational biology and space biotechnology in the past 15 years are addressed briefly.

1 Introduction to SJ-10 Recoverable Satellite

Specialized microgravity and radiation in space induce numerous alterations in physical and biological processes such as the lack of buoyant convection and the boss loss. While a body of evidences has been obtained from those ground-based studies using space environment stimulating platforms, quite a few investigations have been conducted in real space. To further elucidate the underlying mechanisms in the above

E. Duan (✉)
Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China
e-mail: duane@ioz.ac.cn

M. Long (✉)
Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
e-mail: mlong@imech.ac.cn

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processes, a Shijian-10 (shortly, SJ-10) recoverable satellite is designed to conduct the experiments in space and collect the relevant data directly from the mission. At the end of December, 2012, the SJ-10 satellite project has been approved by Chinese Academy of Sciences (CAS). After 40-month technical and scientific preparations, the satellite is launched on April 6, 2016 and recovered back to the Earth on April 18, 2016 successfully. All the samples and specimen have been sent immediately back to the respective laboratories for further studies. This SJ-10 satellite project consists of six systems of Satellite, Rocket Vehicle, Launching, Monitoring and Recovery, Ground Supporting, and Scientific Application. Prof. Wenrui Hu from Institute of Mechanics, CAS serves as the chief scientist, Prof. Bochang Tang from China Academy of Space Technology (CAST) serves as the chief engineer, and Prof. Hejun Yin from the Headquarter of CAS serves as the chief commander and Profs. Ji Wu and Xin Meng from National Space Science Center, CAS serve as the executive and deputy commanders, respectively, of the SJ-10 satellite.

2 Introduction to Ten Space Life Science Projects

Space life science and biotechnology is to conduct the biological and biotechnological experiments of various species in space by utilizing the space hardware in the space vehicle, in which the effect of microgravity and space radiation on biological activities is a crucial issue in this field. The experiments conducted in SJ-10 satellite mission are segregated into two groups. One is physical science under microgravity, consisting of eleven experiments. Another is space life science, being composed of ten experiments. In space life science, three categories are defined as radiation biology, gravitational biology, and biotechnology. In the category of radiation biology, three scientific issues are intended to be addressed in systems biology in space radiation (Dr. Yeqing Sun from Dalian Maritime University), effect of space environment on genome stability (Dr. Haiying Hang from Institute of Biophysics, CAS), and effect of space environment on silkworm development and gene mutation (Dr. Yongping Huang from Shanghai Institutes for Biological Sciences, CAS). In the category of gravitational biology, three issues are focused on effect of gravity on plant growth at molecular level (Dr. Weiming Cai from Shanghai Institutes for Biological Sciences, CAS), flowering in space (Dr. Huiqiong Zheng from Shanghai Institutes for Biological Sciences, CAS), and biomechanics of mass transportation on cell-cell interactions under microgravity (Dr. Mian Long from Institute of Mechanics, CAS). In the category of space biotechnology, four projects are designed to elucidate the maintaining and directed differentiation of hematopoietic stem cells under microgravity (Dr. Yong Zhao from Institute of Zoology, CAS), three-dimensional cell culture and tissue restoration of neural stem cells under microgravity (Dr. Jianwu Dai from Institute of Genetics and Developmental Biology, CAS), mouse early embryo development under microgravity (Dr. Enkui Duan from Institute of Zoology, CAS), and osteogenic differentiation of human mesenchymal stem cells under microgravity (Dr. Jinfu Wang from Zhejiang University). Meanwhile, the related techniques, space hardware and ground-based devices are developed by Shanghai Institute of Technical Physics, CAS (Dr. Tao Zhang), National Space Science Center, CAS (Dr. Yuanda Jiang), and Institute of Mechanics, CAS (Dr. Shujin Sun), respectively. All the payloads work well in space to guarantee the success of the SJ-10 mission.

3 Scientific Issues Addressed

The aforementioned projects attempt, from the viewpoint of space life science and biotechnology, to unravel the sensing and transduction mechanisms of various species under microgravity and space radiation and to develop the novel techniques in stem cell differentiation and embryonic development. Scientific issues are mainly focused on understanding the effect of space environment on evolution of terrestrial life and on the impact of space environment on physiological homeostasis of organisms. Three specific aims are: (1) How do the terrestrial lives sense microgravity and/or space radiation signaling and what are the underlying transduction pathways? (2) How do the organisms adapt themselves to the microgravity and/or space radiation environment? (3) How are the microgravity and/or space radiation resources utilized to promote the perspective of space life science and the development of space biotechnology? The outcomes of these projects would provide the fundamental understandings, propose new concepts, new ideas, and new methodology, and establish the integrated platforms in ground- or space-based studies for space life science and biotechnology. Expected results are to develop numerical simulation platforms and biologically-specific techniques and to further the understandings in sensation and transduction of microgravity and space radiation signaling for plant or animal cells or in tissue histogenesis. The related issues and aims are briefed individually as below (Hu et al. 2014).

3.1 Radiation Biology

The first project in this category, entitled *Molecular biology mechanism of space radiation mutagenesis*, aims (i) to analyze the sequence information of genome methylation and transposon change caused by space radiation and explore the molecular mechanisms of space radiation induced genomic instability; and (ii) to study the proteomics profiles of model organisms caused by different radiation qualities, mine the molecular mechanisms of functional proteins, and to establish the biological systems that evaluate radiation qualities (Wang et al. 2008). Plant and animal model organisms are located at three distinct radiation environments inside the satellite. By monitoring three tissue equivalent detector devices, the space radiation parameters such as absorbed dose, absorbed dose rate, linear energy transfer value, and dose equivalent are detected. The biological materials irradiated by different kinds of particles that belong to the same satellite orbit are then harvested and recovered. System biology analyses such as genome epigenetic scanning and proteomic approaches are conducted to obtain information of biological changes under different radiation qualities and to correlate biological effects with different radiation parameters.

The second project entitled *Roles of space radiation on genomic DNA and its genetic effects*, attempts to elucidate the roles of space radiation on genomic DNA and its genetic effects in the real space environment in two aspects: (i) Space radiation and genomic stability. Genomic stability of wild type and radiation-sensitive mouse cells and fruit flies is investigated in pre- and post-flight or at different time points during the spaceflight. Quantitative parameters of space radiation of genome and its genetic effects are then obtained in the real space environment. (ii) Gene expression profiles and sensitive response genes to space radiation. Gene expression profiles are obtained from the above mouse cells and of fruit flies. Novel and sensitive biological molecules are identified as space radiation markers. This work provides novel information for developing evaluation methods for the risk factors and protection tools against space radiation (Wang et al. 2011; Cui et al. 2010).

The third project, entitled *Effects of space environment on silkworm embryo development and mechanism of mutation*, applies the selected silkworm embryos to pursue the following contents: (i) gene expression pattern of embryo under real space environment; (ii) proteome of silkworm embryo; (iii) mutation discovery and functional analysis; and (iv) embryo development and its characterization. Systematic approaches of the embryo development design and multiple sampling throughout the entire developmental stages are performed under space environment. Multiple platforms of gene expression, proteomics, and functional genomics, are employed to unravel the development characteristics of silkworm in space and to find out the possible mutations through molecular approaches (Miao et al. 2005).

3.2 Gravitational Biology

The first project in this category, entitled *Biological effects and the signal transduction of microgravity stimulation in plants*, focuses on elucidating the effects of microgravity (weightless) environment in space on plant growth and the molecular mechanisms underlined in two specific aims: (i) whether plant's sensation of the weight loss is also mediated by statoliths or other mechanisms; and (ii) whether there are any differences in transduction cascades between weight loss and gravitropic signaling. The hypothesis that the rigidity of the supporting tissue (i.e., the cell wall in plant) is regulated by microgravity is tested to understand how space microgravity affects the rigidity of plant cell wall and the metabolism of plant cell wall, which in turn manipulates the growth of plants (Hu et al. 2005; Cui et al. 2005).

The second project, entitled *Biomechanics of mass transport of cell interactions under microgravity*, attempts (i) to develop a novel space cell culture hardware consisting of precisely controlled flow chamber and gas exchange system and to investigate the mass transport mechanisms in cell growth and cell-cell interactions under microgravity; and (ii) to distinguish the direct responses of cells from those indirect responses via the varied mass transport conditions induced by gravity changes. New data sets on the metabolism, proliferation, apoptosis, differentiation, and cytoskeleton of osteoblasts and mesenchymal stem cells are collected under well-defined mass transfer. This work provides an insight into quantifying the direct cellular responses in space, revealing the effects of gravity on cell-cell interactions, elucidating the mechanisms of cell growth and differentiation in space, and overcoming the methodological bottlenecks of space cell biology studies (Sun et al. 2008; Long et al. 2011; Li et al. 2018).

The third project, entitled *Photoperiod-controlling flowering of Arabidopsis and rice in microgravity*, aims at deciphering how space microgravity regulates the transportation of flowering signals from leaf to shoot apex at molecular level. Using transgenic *Arabidopsis thaliana* and rice plants (expressing FT or Hd 3a gene with the reporter genes GFP or GUS), living fluorescence imaging technique is developed to determine the induction of FT and Hd3a gene expression and floral initiation in shoot apex under long-day and short-day photoperiod condition under space microgravity or in normal gravity on the ground. This work sheds light on regulating mechanisms of photoperiod controlled flowering in both *Arabidopsis thaliana* and rice by microgravity (Zheng and Staehelin 2011; Wei et al. 2010).

3.3 Space Biotechnology

The first two projects, entitled *Three-dimensional cell culture of neural and hematopoietic stem cells in space*, share the same hardware in SJ-10 satellite. They aim to understand whether microgravity environment is suitable for the self- renewal and differentiation of hematopoietic or neural stem cells. Three-dimensional cell culture of hematopoietic stem cells and neural stem cells is conducted in space. With microscopic detection, image transmission, and gene/protein analysis through the recovered samples, the effects of microgravity on the self-renewal/differentiation of two types of stem cells are tested to reveal the characteristics of growth and differentiation of these 3D cultured stem cells under microgravity. The outcomes are crucial in regenerative medicine for treatment of various blood diseases and neural injury, respectively (Cui et al. 2008; Chen et al. 2007).

The third project, entitled *Development of mouse early embryos in space*, attempts (i) to determine whether early mammalian embryo can develop in outer space or not; (ii) to observe the developmental process during space flight by transmitted images of the embryo from the satellite to the ground; and (iii) to investigate a potential molecular mechanism of the early embryo development in space. Using mouse early embryos, the 2-cell or 4-cell stage mouse embryos are cultured in a specialized hardware and the morphological alterations at various developmental stages (4-cell, 8-cell, early morula, compacted morula, blastocyst and hatched blastocyst) of early embryos are monitored by optical microscopy in space. Molecular mechanisms are further tested using recovered fixed embryos. This work furthers the understanding in the beginning of mammalian life and the entire process of reproduction in space (Lei et al. 2011; Ning et al. 2015).

The fourth project, entitled *Potential and molecular mechanism of osteogenic differentiation from human bone mesenchymal stem cells*, aims to examine the potential mechanisms of osteogenic differentiation from human bone mesenchymal stem cells (hBMSCs) in space microgravity in the three aspects: (i) to develop a specialized space hardware and techniques for the osteogenic differentiation of hBMSCs under space microgravity; (ii) to elucidate the capacity of the osteogenic differentiation potential of hBMSCs in space and to identify the effects of space microgravity on osteogenic differentiation of hBMSCs; and (iii) to analyze the underlying signaling pathways and the protein expression in the osteogenic differentiation of hBMSCs in space. This work provides an insight into how space microgravity affects the osteogenic differentiation of hBMSCs through specific signaling pathways and what the molecular mechanisms and the roles of these key molecules are in osteogenic differentiation of hBMSCs under space microgravity (Pan et al. 2008; Shi et al. 2010).

4 Summaries of This Book

This book consists of fourteen chapters, dealing with both scientific and technical advances from SJ-10 satellite mission and also summarizing the recent progresses in the related fields from the worldwide community of space life sciences and biotechnology. Briefly, the book attempts to address the key issues such as (1) how space radiation regulates the biological activities and effects of model organisms (mammalian cells, *Drosophila*, *C. elegans* and silkworm), (2) how space microgravity defines the biological responses and flowering mechanisms of higher plants (*Oryza sativa*, *Arabidopsis thaliana*), (3) what the biomechanical principles of mass transfer under microgravity are in the cell growth (endothelial cells and mesenchymal stem cells), (4) how microgravity governs the early embryonic development of mammalian animal (murine), and (5) whether microgravity environment is able to promote the technologies of directed differentiation and three-dimensional growth of stem cells (hemopoietic, neural, and mesenchymal). Specifically, chapter "Introduction to Results of Life Sciences from SJ-10 Recoverable Satellite" introduces the overview of space life sciences and biotechnology in SJ-10 recoverable satellite. Chapter "System Design and Flight Results of China SJ-10 Recoverable Microgravity Experimental Satellite" introduces the system design and flight performance of SJ-10 satellite. Chapters "Space Radiation Systems Biology Research in SJ-10 Satellite" to "Effects of the Space Environment on Silkworm Development Time" explore space radiation effects. Chapters "Plant Adaptation to Microgravity Environment and Growth of Plant Cells in Altered Gravity Conditions" to "Flowering of Arabidopsis and Rice in Space" exploit gravitational biology effects. Chapters "The Maintaining and Directed Differentiation of Hematopoietic Stem Cells Under Microgravity" to "Effects of Space Microgravity on the Trans-differentiation Between Osteogenesis and Adipogenesis of Human Marrow-Derived Mesenchymal Stem Cells" decipher space biotechnology. Chapters "Facilities and Techniques of Space Life Science" and "Study on Bone Marrow Box, Radiation Gene Box and Integrated Electrical Control Boxes" elaborate the related techniques and hardware. Together with informative protocols, procedures, figures/tables, and colorful images, this book could serve as the reference for senior undergraduates and graduates in space life sciences and biotechnology, or help to the scientists, scholars, engineers, administrative officers, and enthusiast in the related fields. The contents of this book would provide the space-based data in understanding the life activities and growth mechanisms under microgravity and space radiation and promote the technical bases in solving the bottleneck issues in experimental study of space life science and technical development of biotechnology.

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