Bioinformatics and Computational Medicine
ISSN: 3078-7424
DOI: https://doi.org/10.61784/bcm3001

COMPUTATIONAL MEDICINE - COPING WITH THE CHALLENGES OF BIG DATA AND CLINICAL TRANSFORMATION

YunRu Lin
School of Medicine, Shanghai Jiao Tong University, Shanghai 200030, Shanghai, China.
Corresponding Email: zklsmng@163.com

Abstract: As an emerging interdisciplinary discipline, computational medicine aims to use computer science and information technology to cope with the challenges of medical big data and promote its clinical transformation. Computational medicine combines knowledge from multiple fields such as medicine, biology, computer science and data science to analyze and interpret large-scale medical data. Through advanced data analysis and machine learning techniques, computational medicine aims to discover biomarkers of diseases, predict disease risks, optimize treatment plans, etc. The amount of medical data is huge, including electronic health records, medical images, genomic data, etc. Computational medicine processes this data through efficient algorithms. Issues such as data heterogeneity, data quality, data security and privacy are key challenges that computational medicine needs to solve. Computational medicine supports clinical decision-making by mining big data, including personalized treatment, early diagnosis of diseases and risk prediction. Algorithm models based on big data can help doctors better understand disease mechanisms and develop precise treatment plans. Computational medicine tools such as medical image analysis and genomic data analysis can be directly applied to clinical practice to improve the quality and efficiency of medical services. Feedback from clinical trials and practical applications can further optimize computational medicine models and promote their clinical transformation. While responding to the challenges of medical big data, computational medicine is gradually transforming from research results to clinical applications, and is expected to provide more accurate and efficient support for medical services.
Keywords: Computational medicine; Big data; Clinical medicine

1 INTRODUCTION

For a long time, in the field of biomedicine, the knowledge and information provided by the reductionist research method is "fragmented", and it is impossible to piece together a complete picture to fully and truly understand life and disease. In recent years, with the rapid development of medical engineering technology and computer technology, the biomedical field has ushered in the era of big data, and more comprehensive life and disease information has been presented. How to
analyze and apply massive data with high-throughput and high-dimensional characteristics to understand the life mechanism and disease mechanism in a more realistic way, and improve the level of disease prediction, clinical diagnosis and treatment, and health maintenance? It is certain that the theoretical and technical methods of computational medicine and visualization provide a scientific and efficient path for this field.

2 CHALLENGES OF BIOMEDICAL BIG DATA

In 2012, Viktor Mayer-Schūnberger, one of the earliest data scientists who had insight into the development trend of the big data era and a professor at Oxford University, pointed out in his book "The Age of Big Data" that the information storm brought by big data is changing our lives, work and thinking [1]. Big data has ushered in a major era of transformation, and prospectively depicted the changes in thinking, business and management that the big data era will bring. He also believes that the core of big data is prediction. Big data will create unprecedented quantifiable dimensions for human life. Big data has become the source of new inventions and new services, and more changes are ready to take place. The challenges of biomedical big data are mainly reflected in the following aspects:

2.1 Huge Amount of Data

The amount of data in the biomedical field is very large, such as genomic data, proteomics data, clinical medical records and medical imaging data. These data volumes are usually calculated in TB or even PB, which places high demands on storage and computing power.

2.2 Data Heterogeneity

Biomedical data are of various types, including structured data and unstructured data, with various data formats and sources. Integrating these heterogeneous data and conducting effective analysis is a major challenge.

2.3 Data Quality

Data quality directly affects the accuracy of analysis results. Biomedical data may have missing values, erroneous values or inconsistencies, which require data cleaning and preprocessing [2].

2.4 Data Privacy and Security

Biomedical data often contain sensitive personal health information. How to effectively use it while ensuring data privacy and security is an urgent problem to be solved.

2.5 Data Analysis Complexity

The analysis of biomedical data often requires complex biostatistical methods and machine learning algorithms, which places high demands on the professional skills of researchers.

2.6 Explanation and Interpretability

The analysis results need to be understandable and acceptable to clinicians and researchers. Therefore, in addition to the accuracy of the algorithm, interpretability is also an important challenge.

2.7 Knowledge Integration and Interdisciplinary Cooperation

The analysis of biomedical big data often requires knowledge from multiple fields such as biology, medicine, and computer science, and interdisciplinary cooperation is particularly important [3].

2.8 Regulations and Ethical Issues

When using biomedical big data, relevant laws and regulations must be followed and ethical issues, such as genetic discrimination and patient consent, must be considered.

2.9 Clinical Transformation

Transforming the analysis results of biomedical big data into applications in clinical practice requires rigorous validation and clinical trials, and this transformation process is full of challenges.

2.10 Continuous Update and Maintenance

Biomedical data is dynamic and needs to be continuously updated and maintained to ensure the timeliness and accuracy of the analysis results.

In the field of natural science, although the previous reductionist research methods have achieved great success, their shortcomings are becoming increasingly prominent. As stated in the "Complex Systems" column of Science magazine in 1999, "Problems in physics and chemistry can always be understood in terms of atomic physics, cell biology in terms of how protoplasm works, and organisms in terms of the interactions of the cell systems that make up them. We have the best reason to adopt this reductionism: it works [4]. It has been the key to obtaining useful information since the dawn of Western science and has been deeply embedded in our culture through scientists and others." "But the shortcomings of reductionism are becoming increasingly apparent. At least the increasingly specialized branches of disciplines are creating obstacles to the flow of information. Another problem is oversimplification. As the famous scientist Qian Xuesen pointed out in systems science, the human brain, human body, biological, ecological, geographical systems, galaxy systems, etc. are all complex giant systems. The elements or subsystems they contain are of various types, with different natures, and complex and changeable relationships. There are multiple macro and micro levels, and the correlations between different levels are complex [5]. The mechanism of action is unclear. Life activities involve everything from molecules, cells, Different levels, such as tissues, organs, systems, and the entire human body. Therefore, what we need to study are the different activities of multi-level complex networks and the complete biological complex systems that organize them together. The knowledge obtained from the reductionist research method lacks, at least partially, the information on the interactions between different components in the life system. In addition, the nonlinear characteristics of the structure and function of the life system along the time axis make it easy to understand why we still have few ways to predict and cure many diseases such as stroke and cancer. In recent years, with the progress and widespread application of genomics, proteomics, metabolomics, and imaging technology, massive data have been obtained through various technologies, and the biomedical field has ushered in the era of big data. When faced with massive data with high throughput and high dimensionality, the traditional biomedical research model is no longer appropriate. While people have the opportunity to study life or its subsystems from a holistic perspective, how to scientifically store, transmit, analyze, interpret, and apply the massive data obtained through various technologies to serve disease prediction, clinical diagnosis and treatment, and health maintenance has become an urgent problem to be solved in the biomedical field.

3 CURRENT STATUS AND PROSPECTS OF COMPUTATIONAL MEDICINE

(1) Computational medicine Computational medicine is a science that uses computers and application software to conduct quantitative analysis, mathematical model construction and computer simulation of medical problems in response to the needs of medicine [6]. It is an emerging interdisciplinary subject that combines medicine and computational science. It is a new interdisciplinary field that involves many disciplines such as medicine, biology, engineering, computer science, physics and mathematics. It has developed rapidly in recent years and is applied to almost all levels from molecules, cells, tissues, organs, systems to the whole. Its main task is to achieve the recognition and understanding of life mechanisms and disease mechanisms through scientific computing, so as to achieve the purpose of predicting diseases, designing diagnosis and treatment plans, evaluating efficacy, developing and evaluating new drugs, and "individualized" diagnosis and treatment and health maintenance.

(2) Establishment of large databases The National Institutes of Health (NIH) 1000 Genomes Project database has a total data volume of 200 TB is the world's largest human gene variation data set [7]. On March 29, 2012, all the data in the database were made available to the public for free. More scientists will use this data to more quickly study the relationship between genotypes and diseases such as cancer and diabetes. In early 2013, the University of Pennsylvania School of Medicine built and put into use the first TB-level database to fulfill its promise to provide "precision medicine". The research database combines patient care information obtained from the medical center's clinical trial management system and laboratory cancer genomics data. Researchers will be able to access the data through an Internet connection in their own laboratories. In January 2014, Stanford University in the United States and Oxford University in the United Kingdom will form a team of experts in genomics, epidemiology, public health care, clinical medicine, computer science, informatics, statistics and bioinformatics to cooperate in the research of biomedical "big data" to promote human health and reduce medical costs. In January 2014, Central South University in my country launched the "Xiangya Clinical Big Data Construction" project to promote the development of smart medicine, personalized medicine, hospital refined management, clinical research, translational medicine and basic medicine. In addition to the typical, intensive databases mentioned above, there are many scattered medical information databases in universities and medical institutions around the world. How to classify, integrate, transmit, share, and develop global biomedical information resources is a realistic problem facing the fields of medicine, informatics, engineering, and computer science.

(3) Development direction of computational medicine Computational anatomy is an emerging discipline that focuses on the quantitative analysis of biological morphological variations. It is a development direction that closely combines anatomy and imaging, involving anatomy, imaging, graphics and imaging, computer science, and mathematics. Computational anatomy technology involves graphics and image processing based on anatomical knowledge, digital geometry, mathematical modeling, and virtual reality. The application needs in the fields of human structure modeling, surgical planning, stereotactic surgery, precision radiotherapy, image-guided surgery, robotic surgery, and evaluation of the morphology and function of the nervous system have promoted the rapid development of research in this direction, achieved definite results, and quickly transformed into clinical applications. Many research institutions around the world are constantly deepening their research in this field. In June 1999, Scientific American magazine published a case of precise resection of a brain tumor using a combination of computational anatomy, virtual reality and image navigation technologies. This project was jointly researched, planned and designed by the Surgical Design Laboratory of Brigham and Women's Hospital of Harvard Medical School and the Computer Vision Research Group of the Artificial Intelligence Laboratory of MIT. It is a landmark case of the application of computational anatomy results in surgical operations. In addition, there are computational physiology, computational pharmacology, computational epidemiology, computational immunology and other directions.

(4) Development of computational medicine The Whiting School of Engineering and the School of Medicine of Johns Hopkins University jointly established the Institute of Computational Medicine, which is committed to using computational modeling to predict how protein mutations trigger the development of breast cancer; compare the shape of brain structures of healthy and diseased patients, find differences that may lead to brain diseases and better diagnosis and treatment methods, and study how dangerous arrhythmias are initiated and maintained. The computational model of heart function is used to determine how to best use defibrillators to stop these irregular heart rhythms. The University of Bristol in the UK focuses on various omics technologies for common metabolic diseases (such as diabetes and cardiovascular disease). The University of Colorado, the University of Washington, the University of Michigan and the University of Hamburg in Germany focus on the application of virtual visual people in biomedical research and education. The University of Michigan also cooperates with the US military to develop virtual soldiers. The China-Europe Alliance Computational Medicine Center of the Chinese Academy of Sciences is committed to computational neuroanatomy, image-based brain connectome [8], imaging genetics, imaging and genetic research on brain diseases and cognitive disorders. The Third Military Medical University and Southern Medical University have built 8 high-precision Chinese digital human data sets and conducted organ tissue modeling; Huazhong University of Science and Technology is conducting physiological group research based on digital human bodies; The Chinese University of Hong Kong has conducted in-depth research on 3D rendering of digital human organ structures, virtual acupuncture and virtual surgical models and systems. Shandong University has established a new standard for the

digital model of Chinese liver segments and the division of liver segments, and Xiamen University has built a virtual eye model. Since 2004, the Computational Medicine and Visualization Laboratory of Bengbu Medical College has been focusing on the research of stereoscopic 3D reconstruction and visualization of brain sulci and gyri, and has built a 3D positioning data set and visualization model of important brain sulci in vivo based on thin-layer MRI.

4 CONCLUSION

Computational medicine is a cutting-edge science that integrates multiple disciplines such as biology, medicine, computer science and data science. Its core purpose is to meet the challenges of biomedical big data and successfully transform research results into clinical applications. The following is a conclusion on the clinical transformation of computational medicine in response to big data challenges [9]:

4.1 Driven by Technological Progress

The development of computational medicine has benefited from technological progress, especially the improvement of computing power, innovation of algorithms, and enhancement of data storage and processing capabilities, which provide a basis for processing and analyzing large-scale biomedical data.

4.2 Implementation of Precision Medicine

Through computational medicine methods, we can achieve a deep understanding of disease mechanisms, as well as the advancement of precision medicine and personalized treatment, thereby improving the efficiency and quality of disease prevention and treatment.

4.3 The Necessity of Interdisciplinary Cooperation

The successful transformation of computational medicine requires close cooperation among experts in biology, medicine, computer science and other fields, as well as interdisciplinary education and talent training.

4.4 The Importance of Clinical Validation

The clinical transformation of computational medicine models requires rigorous validation and clinical trials to ensure their safety and effectiveness [10].

4.5 Policy and Regulatory Guarantees

In order to promote the development and application of computational medicine, it is necessary to establish a corresponding policy and regulatory framework to protect patient privacy and data security, while encouraging innovation and transformation.

4.6 Continuous Updating and Optimization

Computational medicine models need to be continuously updated and optimized based on clinical feedback and new data to maintain their accuracy and adaptability.

4.7 Infinite Possibilities in the Future

Computational medicine has shown great potential and broad application prospects in the process of responding to big data challenges and transforming to the clinic, and is expected to bring revolutionary changes to human health.

In short, the development of computational medicine is an important way for the biomedical field to respond to big data challenges, and its successful transformation to the clinic will have a profound impact on improving the quality and efficiency of medical services and promoting the development of medical health.

There is reason to believe that with the deepening of the cross-disciplinary integration and integration of related disciplines, and centering on the major needs of national scientific and technological development, computational medicine, an emerging discipline, will surely grow rapidly in my country, serving the correct understanding of life and the "individualized" diagnosis and treatment of diseases.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Jeff Cooper. Waste: Striving for a more sustainable future. Local Environment, 2019.
[2] Fairley Mike. "Green" initiatives point to a more sustainable label future. Converting Magazine, 2006.
[3] Liu Guqun. Discussion on the Auxiliary Role of Multimedia in Chemical Experiment Teaching. CD Technology, 2009, 62.
[4] Li Anfeng, Lu Wei, Zhao Feng. Micro experiments and the reform of new chemistry curriculum standards. Chemistry Teaching, 2005(10): 4-6.
[5] David Pencheon. Delivering a more sustainable NHS: key strategies and policies. Journal of Renal Nursing, 2024: 589-590.
[6] Zhou Na. The Transformation of Teaching Methods for Chemistry Teachers in the Reform of New Curriculum Standards. Journal of Anhui Education College, 2004(3): 111-112.
[7] Chen Shijie, Li Jinlong, Bai Liming, et al. Research and Practice of Inorganic Chemistry Experimental Teaching System Based on Innovation and Entrepreneurship Talent Cultivation. Journal of Chemical Engineering, 2017, 31(7): 53-54.
[8] Han Jingchang. How to cultivate students' experimental exploration ability in chemistry teaching. Journal of Liaoning Education Administration College, 2007 (1): 156-158.
[9] Chen Shijie, Li Jinlong, Bai Liming, et al. Research and Practice of Inorganic Chemistry Experimental Teaching System Based on Innovation and Entrepreneurship Talent Cultivation. Journal of Chemical Engineering, 2017, 31(7): 53-54.
[10] Yasantha Abeysundara, Sandhya Babel. A quest for sustainable materials for building elements in Sri Lanka: Foundations. U.G. Environmental Progress & Sustainable Energy, 2016.