The Impact of Big Data on Precision Medicine: Prospective and Challenge

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Abstract. Precision medicine has emerged as a transformative paradigm in modern healthcare, leveraging advances in big data analytics to tailor medical treatment to individual characteristics or individuation. This paper explores the pivotal role of biomedical big data which integrating electrical clinical data, imaging, phenotypic, molecular and even social economic behavior in precision medicine. Precision medicine empowered with big data can overcome the limitations of traditional medicine, such as low data efficacy, inefficient diagnostics, and reliance on subjective physician experience. With the advent of 6G networks, real-time health monitoring and dynamic data integration are becoming feasible, further accelerating the implementation of precision medicine. However, significant challenges remain, including infrastructure development, data standardization, privacy preservation, and ethical surveillance. This article discusses current integrations of big data in medical practice, which glean light on achieving truly personalized, data-driven healthcare.

Keywords: Precision medicine, Big data, Artificial intelligence, Healthcare innovation

1 Introduction

Precision medicine represents a revolutionary shift from the traditional empirical medical healthcare, instead focusing on individualized prevention, diagnosis, and treatment strategies[1]. This paradigm is achieved possible by the exponential growth of biomedical big data and sophisticated AI algorithms capable of deriving meaningful insights and valuable data from complex, massive and disorganized data. Traditional medical practices often based on fragmented data, inconsistent standards, and operational inefficiencies[2]. The integration of large-scale, multi-modal data with machine learning models offers new pathways to overcome these limitations and shed light on treatment of difficult diseases. It can be optimistically foreseen that in the future, with the continuous integration of information technologies such as artificial intelligence and big data,

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the construction of high-quality large-scale queues, the development of life omics technology, and the gradual maturity of disease precision prevention and control, as well as the construction of composite talents, the innovation mechanism of industry university research, and the improvement of related policy systems, precision medicine will inevitably show a more vigorous development trend[3]. Herein, the impact of big data on precise medicine is discussed in this text, as well as challenges and prospectives in the future.

2 The Role of Biomedical Big Data

Biomedical big data encompasses diverse data types, including electronic health records (EHRs), medical imaging, genomic sequences,, environmental exposure metrics, and real-time behavioral data. These datasets enable a holistic view of patient health, facilitating early disease detection, personalized therapeutic interventions, and improved prognostic accuracy[4]. For example, AI-driven image recognition systems can identify malignancies in radiological scans with higher precision than human experts, which is increasingly showing advantages in computerized tomograph (CT)/ Magnetic Resonance Imagine (MRI) diagnosis and pathological examination, because human eyes cannot obtain as much effective information as machines. With the deepening development of genome sequencing technology and the rapid progress of new generation information technology, the integration of bioinformatics and big data technology has been increasingly promoted, this allows genomic data analytics for targeted cancer therapies based on mutational profiles. Owing to the in-depth exploration of human genomes and disease-related genes, the combination of molecular level detection methods and bioinformatics analysis with big data science has become a reality for cancer prevention, diagnosis, and treatment at the genetic and molecular levels (Table 1).

Scientists from the United States, Britain, France, Germany, Japan, and China jointly released a draft of the human genome in 2001. In April 2003, the sequencing work of the Human Genome Project was completed, and the final completed map sequenced 95% of the human euchromatin region with a sequence error rate of less than one in ten thousand. On the basis of great achievements in the exploration of human genome science, Professor Clayton Christensen of Harvard University proposed the concept of precision medicine based on molecular diagnosis in 2008. Clayton believed that molecular diagnosis is more direct and accurate than empirical diagnosis[5].

The achievement of these accomplishments would have been unimaginable without the development of information science such as big data.

3 Technological Enablers: AI and 6G Networks

Artificial intelligence, particularly machine learning and deep learning, serves as the backbone of modern precision medicine. AI models can integrate and interpret heterogeneous data sources, identify patterns, and generate predictive models for clinical decision-support. Meanwhile, the ongoing development of 6G communications promises ultra-low latency and high bandwidth, enabling real-time data transmission from wearable devices, remote sensors, and telemedicine platforms [6,7]. This infrastructure is critical for continuous health monitoring and timely intervention.

Table 1. The impact of big data on precise medicine

<table>
<tr><th colspan="5">Big Data Collecting</th><th colspan="4">Big Data Analysis</th></tr>
<tr><td colspan="5">Electronic Health Records(EHR)
clinical history, examination, characteristic; life style, Lab reports, et al</td><td colspan="4">Database Mamagement
useful database selecting and cloud storage</td></tr>
<tr><td colspan="5">Image-related Information
CT/MRI; Ultrosound, histopathological Examination, X-ray, et al</td><td colspan="4">Database Processing
unstrctured to structured
machiine learning
deep learning</td></tr>
<tr><td colspan="5">Hight Omics Data
Genomics, proteomics, Metabolomics, et al</td><td colspan="4">Systymic Analysis
biological network
network-aided multi-omic data integration and analysis</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td colspan="9">Precision Medicine</td></tr>
<tr><td>Patient Profiling</td><td></td><td>Biomarker Investigation</td><td></td><td>Patient Stratification</td><td></td><td>Improved Diagnosis</td><td></td><td>Precise treatment</td><td></td><td>Precise Prognosis</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td colspan="9">Personalized therapy</td></tr>
<tr><td colspan="4">Molecular Profiling</td><td colspan="2" rowspan="3"></td><td colspan="3">Treatment option 1</td></tr>
<tr><td colspan="4">Benefit-Risk Prediction</td><td colspan="3">Treatment option 2</td></tr>
<tr><td colspan="4"></td><td colspan="3">Treatment option 3</td></tr>
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4 Current Applications and Integrations

The first and foremost impact of big data technology on medical service models will be the ability to replace a large amount of mechanical, repetitive, and labor-intensive work in tedious medical work. The work that requires a large amount of film reading in pathology and imaging departments is highly likely to be replaced by artificial intelligence; The vast amount of medical literature and clinical evidence generated constantly will be found through big data and artificial intelligence technology to obtain the most direct and reliable information. Previously considered the most labor-intensive tasks by clinical doctors, such as consultation, medical record writing, and follow-up observation, will be easily achieved in the future through methods such as speech recognition, natural language processing, and human-computer interaction.

The advent of 6G wireless technology is also poised to revolutionize the field of remote surgery, or telesurgery, by overcoming the critical limitations of current networks. While 5G has demonstrated the potential for remote procedures through enhanced mobile broadband and reduced latency, 6G promises a transformative leap with its foundational pillars: sub-millisecond latency, ultra-high reliability, immense data capacity, and integrated sensing capabilities [7]. Surgeons in Shanghai can provide surgery for patients in the Xinjiang Uygur Autonomous Region through remote surgery, which greatly facilitates patients.

This next-generation network will enable a truly seamless and immersive surgical experience[9]. Haptic feedback systems will transmit precise tactile sensations in real-time, allowing surgeons to "feel" tissue resistance during robotic procedures, a feature currently constrained by network limitations. Furthermore, the massive bandwidth of 6G will support the simultaneous streaming of ultra-high-definition video, real-time imaging data like MRI/CT scans, and advanced AI-driven analytics directly into the surgeon's console. This creates a comprehensive sensory environment for making critical decisions from thousands of miles away.

Moreover, 6G's reliability and security features are paramount for patient safety, ensuring zero tolerance for data loss or connection drops. The technology will also facilitate complex multi-surgeon collaborations across the globe, democratizing access to expert care. In conclusion, 6G is not merely an incremental improvement but a key that will unlock the full potential of telesurgery, making it a safe, reliable, and standard practice for future healthcare systems and greatly improving global health equity.

These applications demonstrate how big data and AI are already reducing diagnostic errors, optimizing treatment plans, and improving precise medicine.

5 Challenges and Limitations

Despite promising advances, key challenges impede the full realization of precision medicine. The vast amount of multi life omics, radiomics, various phenotype and biological marker data from each individual poses a technical bottleneck for achieving comprehensive and holistic analysis, making it difficult to obtain truly effective individualized data [8].

In fact, the precision medicine model also ignores individual spiritual factors, which involve various aspects of everyone's life and directly affect patients' attitudes towards diseases and the choice of diagnosis and treatment plans. The precision medicine model is not yet able to fully get all the information of every patient. In addition to the physical information of multi omics, it is also necessary to understand each patient's needs, values, behavioral habits, beliefs, and cognitive levels. Only by integrating these data with individual biological data can precise medical services be truly provided.

In addition, the wealth of available information is often in unstructured formats, thought it be of immense value. However, converting unstructured data into structured one and/or combining them to generate knowledge has been irecognized as a major challenge in biomedical big data application. It has been emphasized that with development in new devices, technology and 6G network, we are drowning in more data relating to health care and biomedical information. All that can impede the process of converting biomedical big data to new knowledge which can be used to improve individual precise diagnosis, treatment and prognosis, as well as population healthcare[10].

In the IoT era, another major challenge which big data presents is personal information privacy. It is a very sensitive topic. How to collect, store and share the data without violation of privacy has been a dilemma and focus in the process of linking big data to precise medicine[10].

Infrastructure Costs: Deploying and maintaining 6G networks and scalable cloud systems demands significant investment. In contrast to conventional medicine model, governments must evaluate the big-data-based solutions' long- term cost-effectiveness and return on investment.

6 Future Prospectives

The exciting rapid development of precision medicine based on big data and AI is leading us towards an era where healthcare is more predictive, preventative, personalized, and participatory. The future of precision medicine will be the integration of multiple omics, not just genomics, but the fusion of various biomedical data such as genomics, proteomics, metabolomics, etc[11]. AI and machine learning technologies, especially deep learning, are crucial for extracting meaningful information, identifying biomarkers, predicting disease risks, and optimizing treatment plans from these massive and complex data[12]. Wearable devices and remote monitoring technology can continuously collect individual physiological data, activity levels, and environmental exposure information, which enables real-time and dynamic tracking of patients' health status, providing a large amount of phenotypic and environmental data beyond traditional clinical settings, making intervention measures more timely, more personalized and more precise.

7 Conclusion

The fusion of big data and AI holds immense potential to revolutionize precision medicine, making personalized healthcare increasingly attainable. However, overcoming technical, ethical, and infrastructural hurdles is essential for sustainable integration. Collaborative efforts among researchers, clinicians, policymakers, and technology experts will be crucial in shaping the future of healthcare.

Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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