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The metaverse in current digital medicine

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ABSTRACT

The metaverse has entered people's horizons through virtual reality, digital twinning, the Internet of Things, blockchain technology, etc. In the current healthcare system, the management of chronic diseases, such as chronic obstructive pulmonary disease (COPD) and obstructive sleep apnea-hypopnea syndrome (OSAHS), still faces challenges, such as uneven distribution of medical resources, and difficulty in follow-up, overburdening of specialists, and so on. However, metaverse medical platforms incorporating advanced AI technologies, such as industrial-scale digital twins, may address these issues. In this article, we discuss the application prospect of these technologies in digital medicine and the future of the medical metaverse.

Contents

Introduction

The metaverse is a concept defined two decades ago. But in 2021, it was rapidly emerging, and some consider it the next ver-

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sion or even the ultimate form of the Internet. Currently, we can regard the metaverse as a ternary society based on digital technology. People participate with digital identities, and the ternary community integrates humans, machines, and materials. The ideological concept comes from the novella *True Names* by American mathematician Professor Vernor Vinge in 1981, which creatively conceived of a virtual world that can be entered and participated in through a brain-computer interface. Its concept was formally proposed in the novel *Snow Crash*, composed by American science fiction writer Neal Stephenson in 1992. It describes a generation of Internet people who perceive and interact in a cyber world parallel to reality through avatars.[1–2] The rise of the metaverse has brought infinite possibilities to all walks of life. The first concerns leisure and entertainment. Video games are the key track for content development and user traffic in the metaverse. On October 28, 2021, via social media, Mark Zuckerberg announced that Facebook had changed its name to Meta to align the business with the emerging computer-based metaverse.[3] Additionally, the metaverse could impact journalism,[4–5] the traditional retail industry,[6] and art.[7] It could also change the nature of exhibitions at museums through the use of various digital technologies, so on.[8].

Over time, the spectrum of diseases prevalent in society has changed. Chronic non-communicable diseases (referred to as chronic diseases), such as cancer, chronic obstructive pulmonary disease (COPD), diabetes, cardiovascular disease, and asthma, have become a significant threat to human health. Consequently, the prevention and management of chronic conditions need to be strengthened.[9] For example, in the management of COPD, patients are still faced with a severe shortage of general practitioners. Large public hospitals are overwhelmed, specialists are overburdened, community hospitals are not taken seriously, and the population lacks knowledge of medical issues.[10] Many different problems challenge the traditional medical environment and healthcare models. The emergence of the metaverse concept may provide new directions for healthcare. Along with the popularization of intelligent terminals, the improvement of 5G, blockchain, and other infrastructures, the maturity of virtual reality, augmented reality (VR/AR), and other virtualization technologies, the natural world and the virtual world are becoming integrated.[3] This article will discuss the application of these digital technologies in healthcare that may help address the challenges and the future of the medical metaverse.[11].

Definition of the medical metaverse

The development of the medical metaverse (*meta*-medicine) will go through four stages (Fig. 1).

1. Holographic construction

The first stage will be to build a static geometric model of the entire virtual world, including hospitals, medical equipment, and other objects. We can divide these things into three main elements: events, scenes, and people. For example, in a typical surgical scene, the indoor environment and medical equipment constitute the "scene," and patients and medical staff include "people." "Events" consist of dynamic data and information generated during the interactions between people and people or between people and scenes.

2. Holographic simulation

The dynamic process of meta medicine will be constructed to make the virtual world approach the natural world in infinite detail. Along with the development of technology, on the one hand, it will continue to improve its fidelity at the physical level, coarse and fine-grained level, and interaction level. On the other hand, it will be connected with medical information and data systems, such as PACS systems. With the help of real-time motion capture and multi-sensor device information interaction, digital avatars of patients and doctors will provide real-time and intuitive feedback on accurate data and information.

3. Fusion of virtual and real

With the continuous improvement of computer simulation technology, digital technology will make the virtual medical world seem more real. Thus, in building a mixed medical reality (MR) world, the boundary between the virtual and real worlds will be broken. For example, in an outpatient setting, a doctor can communicate with a patient wearing an XR device. Through real-time identification, tracking, and information interaction, patient-related information and data will be retrieved in real-time and presented as a superimposed reality, forming a new relationship with the current natural environment.

4. Virtual-real linkage

Many new medical methods and types of medical equipment and facilities will be created through further development of computer simulation technology, brain-computer interfaces (BCI), artificial intelligence (AI), and other technologies. The changes in medical processes in the real world will follow technological development. Through transformations, medical interventions in the two planets will gradually produce more intersections and finally give birth to new concepts and methods in the era of *meta*-

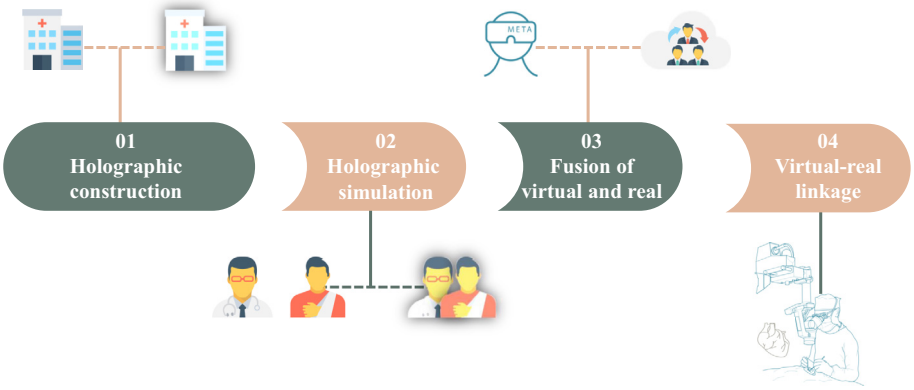

Fig. 1. The four stages of the Metaverse in Medicine.

medicine. The *meta*-medical world will assist in supplementing and improving medical processes in the real world. We will be able to observe the physical space through the information space and also transform the physical space through the information space.

Meta-medicine will have three major characteristics that distinguish it from traditional medicine.

1. Interaction of all things.

Patients and doctors can access the digital world through various types of hardware and edit it in real-time, with everything in the real world being interconnected with the virtual world.

2. Integration of virtual and real.

Meta-medicine will closely integrate the virtual and the real through economic systems, social systems, and identity systems so that patients and doctors have the same richer and more intuitive perception in the three-dimensional world of real and virtual.

3. Decentralization.

Blockchain technology could be involved in the certification, authentication of rights, distribution, trade, use, liquidity, and authentication of virtual identities in digital medical resources and realize the intelligent management of digital rights.[1].

Users, technology, and information are the three dimensions of the metaverse. When applied to *meta*-medicine, patients and doctors are the two most important user groups. Everyone will have their own "digital identity" in the virtual world through digital twins. Real-time patient information, imaging data, and other features will shape the digital avatars of the *meta*-medical world. Doctors and patients will communicate through their respective avatars, breaking time and space constraints. On this basis, the digital world will have greater freedom than the real world, giving us more dimensional observation perspectives, changing the manner of communication and interaction, and allowing us to reshape "reality" in the world of *meta*-medicine.

The realization of *meta*-medicine will be contingent on a reliable technical system, which will be built on Web3.0, a "traversing" and "distributed" Internet, which will be constructed in five levels (Fig. 2 and Table 1).[1] The 5G network environment and the Internet of Things are the foundation of network connectivity. For example, the Internet of Things medical research on respiratory diseases in China has accumulated considerable experience, some of which has been used in clinical practice. Artificial intelligence has assisted early diagnosis of lung cancer, management of chronic obstructive pulmonary disease, asthma, and other chronic diseases. Also, it includes intelligent auxiliary diagnosis and treatment of viral pneumonia, etc.[12] Cloud computing and edge computing have laid a solid foundation for computing power at the data processing level. Mass intelligent analysis of medical information is carried out through the cloud under the cloud computing framework, which retains the "cloud terminal framework" and the deeper processing of big data. At the authentication level, blockchain technology (the bottom of the technology) and the non-fungible token (NFT) system (the top of the application) will provide the technical foundation for the orderly operation of the production, confirmation, and transaction of digital resources in the metaverse.[13].

Characteristics and main advantages of the medical metaverse

The most notable feature of the metaverse is the fusion of real and virtual space–time, which is different from the traditional digital medical model (Fig. 3).[14] Therefore, regarding virtual-real interaction, the realization of the metaverse will rely on a powerful virtual-real interaction interface, which will complete the transition process from a traditional plane interaction to natural interaction. The achievement of the digital parallel world of *meta*-medicine will be inseparable from developing the related hardware (Fig. 4).[1] IoT devices, such as extended reality (XR) technology and brain-computer interfaces (BCI), enable communication between users and information in virtual and natural spaces. XR integrates various technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). When the virtual medical environment is infinitely close to the natural medical environment and reaches the level of holographic construction and simulation, VR will be able to provide patients and doctors with a fully immersive medical experience. An immersive virtual environment will pro-

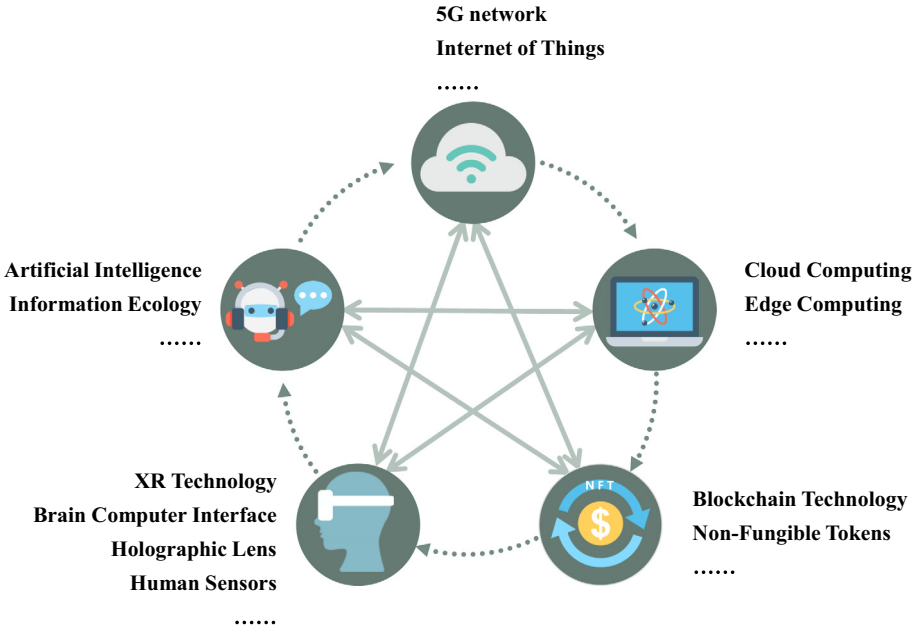

Fig. 2. Five levels of the medical metaverse technology system.

	Technology	Application
Internet Connection	5G network Internet of Things …	Assisted early diagnosis of lung cancer through artificial intelligence, management of chronic diseases such as chronic obstructive pulmonary disease and asthma, intelligently helped diagnose and treat viral pneumonia, etc.
Data Processing	Cloud Computing Edge Computing …	Mass intelligent analysis of medical information between patients and doctors through the "cloud" under the cloud computing framework.
Authentication	Blockchain NFT …	Realize the healthy and orderly production, operation, confirmation, and transaction of digital resources in the metaverse. And the immutability and interoperability of digital assets.
Virtual-Real Interaction	XR Technology BCI Holographic Lens Organoids and Organ Chips …	Provide patients and doctors with a fully immersive medical experience, and a virtual medical environment that is infinitely close to the natural medical environment.
Content Production	AI Cloud Rendering Technology…	Real-time creation of disease information according to the development of the patient's disease course and timely feedback of the doctor's diagnosis and treatment information significantly improve content production efficiency.

Fig. 3. Traditional digital health - plane interaction.

Fig. 4. Metaverse in Medicine - Natural Interaction.

duce new treatments for some psychological diseases. Studies have shown that the VR environment can change psychological problems such as depression, anxiety, cognition, and even social functions.

Additionally, there is empirical evidence of VR-based treatments for mental diseases such as dementia, mild cognitive impairment (MCI), schizophrenia, and autism.[15] Floreo has developed a novel mobile VR platform that aims to create a behavioral therapy metaverse.ca virtual world. A virtual world teaches social, behavioral, communication, and life skills to individuals with Autism Spectrum Disorder (ASD), ADHD, Anxiety, and other neurodiverse conditions. Advances in virtual reality (VR) technology offer new opportunities to design supports for the core behaviors associated with autism spectrum disorder (ASD) that promote progress toward optimal outcomes.[16] There is also great potential for medical education. AR technology relies on recognition and tracking algorithms to identify objective objects and environments, helps superimpose virtual information on the real world to achieve virtual and real integration, and enhances and improves the efficiency of our cognition of things. Doctors, especially surgeons, can use augmented reality visualization aids to explain complex medical phenomena to patients through 3D imaging. BCG analysis shows that by 2024, augmented reality technology for training and simulation in medical control environments will account for 18.9% of the expanded reality market. Such as Immersive Touch surgical simulation technology; Metro Health companies have successfully applied XR technology to the medical field. MR can realize virtual-real switching and achieve higher-level virtual-real integration through immersion and computer vision. Medical robots could become another channel for connecting *meta*-medicine by simulat-

ing the physical body, transforming the virtual world and the real world through natural interactive language, and realizing a virtual-real linkage. Research on and applying brain-computer interfaces in the medical field are also increasing. By combining the real and the virtual to create a virtual environment for human–computer interaction, a direct communication, and control channel is established between the brain and external devices, promoting the exchange of medical information in *meta*-medicine. In addition, more advanced medical devices and digital technologies, such as holographic lenses (HoloLens 2), human sensors (ReSkin), organoids, and organ chips, will tremendously enhance the user's sense of immersion and bring users a new *meta*-medical experience.

In terms of content production, the formation of the metaverse information ecology will depend on an efficient content production mechanism. Through a programmable rendering pipeline and voxel to make up for the defects of the grid model, 3D scanning and dynamic point cloud technology can quickly build digital assets. With the development of hardware rendering capabilities and real-time rendering engines, combined with cloud rendering technology, the application of these high-precision digital assets will no longer be limited by computer terminals. Through algorithm training, artificial intelligence can create real-time disease information according to the patient's disease course development and provide timely feedback on the doctor's diagnosis and treatment information. This will dramatically improve the efficiency of content production and maintain the information ecology of *meta*-medicine through the generation of a large amount of high-quality information. Natural interaction is a new interaction between people and the *meta*-medical world. Information is the core resource of the *meta*-medical comprehensive environment, and social networks, the Internet, and the Internet of Things are the main media of the information movement [1]. The physical world and the human world are connected through social networks.

Doctors can obtain objective information on patients through imaging technologies, such as CT and MRI, transform them into knowledge and intelligence through subjective consciousness, and then feed new data into the real world in different forms. Make information flow entirely between people and objective entities and between people. The human world and the information world are connected through the Internet, and the development of the Internet has transformed traditional medicine into digital medicine. The bridge between the physical world and the information world is the IoT. By combining communication technology and smart mobile devices, the Internet of Things can play a significant role in healthcare. All information is constantly in the process of production, adoption, and exchange.

Application and issues related to the medical metaverse during the global pandemic

The Corona Virus Disease 2019 (COVID-19) pandemic has had a significant global impact on healthcare systems, sending a shockwave through traditional healthcare systems through unprecedented lockdowns and enforced physical distancing. Therefore, it has accelerated the adoption of digital technologies such as mass population screening, rapid contact tracing, supply chain management for vaccines and drugs, telemedicine consultations, and e-commerce. The pandemic has advanced the research and development of digital health and has added more possibilities to the medical metaverse.[17] In the context of the COVID-19 pandemic, cloud technology has provided data storage and computing resources to help improve health care's safety, quality, and efficiency.[18] The Internet of things is beneficial for remote monitoring or mobile medical treatment. Big data and artificial intelligence can help promote COVID-19 precautions and people tracking. Mobile maps, cell phones, mobile payment apps, and social media have allowed the collection of real-time data on people's locations, and these data have been used to build machine learning models. These help predict the regional spread dynamics of SARS-CoV-2, guide border inspections and surveillance, and have become an essential tool for drug reuse or repositioning.[19–20] In addition, blockchain technology enables these sensitive data to be more easily verified and transparently managed. It can also confirm COVID 19-negative immune status or provide a secure, distributed environment.[21] Personal protective equipment, essential drugs, and supply chain management of COVID- 19 vaccines have been under greater scrutiny for medical data sharing and remote medical management.[19].

Although the advancement of digital technology has changed how we interact with the natural world and even redefined the real world, there are also many hidden dangers. The first is the issue of personal privacy. In medical care, protecting patient privacy is a fundamental obligation of medical personnel. But the application of technologies such as the Internet, cloud data, and VR may put patients' privacy at risk in ways we cannot predict.[22] The privacy threats can be broadly categorized as threats to informational privacy, threats to physical privacy, and threats to associational privacy.[23] So it requires the metaverse to provide various tools and techniques by which a user may preserve privacy. For example: Provide a means for a user to confuse observers with noise and deceptive data. Allow the user to become "invisible" to others for some time. Allow a user to inhabit a private copy of some part of the virtual world so that the user may interact with the personal copy unseen by others. These techniques will not be perfect but learning how to measure their efficacy is essential.[22] In addition to privacy in the real world, digital avatars of people will be bound by the privacy rules of the medical metaverse.

Avatars can affect virtual worlds, so there may also be malicious human users who control avatars to engage in deception and unethical behavior. They could invade patient privacy and even tamper with virtual information, affecting real life. Secondly, the interoperability of *meta*-medicine aims to create a more open and decentralized world. The device mainly relies on *meta*-medicine is AR/VR,[24], which will not increase the financial burden on patients. The metaverse economy is a creator-driven system jointly created by many users. Their designs add value to the metaverse, creating a fully interactive environment where medical procedures take place and a more realistic simulation of reality. Based on this comprehensive advantage, it is enough to achieve a more extensive effect at a lower cost in the *meta*-medicine. The gradually maturing blockchain technology will be applied to the metaverse as the technical basis for purchasing virtual goods and services.

Nonetheless, how digital assets are unified and managed is still worth consideration.[13] Finally, technical standardization is the basis for realizing the interoperability of various platforms in the metaverse media facing the public need a unified technical standard to be widely adopted. International organizations such as the "Open Metaverse Interoperability Group" (OMIG) are establishing relevant standards.

Future directions

The emergence of the metaverse will bring infinite possibilities to healthcare and promote digital or precision medicine development. The technological basis for realizing the metaverse is the advancement of digital technologies such as 5G data, digital twinning, artificial intelligence, virtual reality, and blockchain technology. Complex medical knowledge and data will be presented intuitively. High-cost medical collaboration, experiments, teach-

ing, and other activities will be remotely driven through digital avatars in an immersive environment. Patients and doctors will use "digital avatars" to produce, adapt and exchange information in the metaverse, and finally achieve the realm of virtual-real integration and virtual-real linkage. However, the continuous development of digital technology also inevitably brings some hidden dangers. The medical field is different from other fields and has unique ethics and rules. The issue still worth exploring is how to grasp the boundaries of *meta*-medicine, protect patients' privacy and personal information, and formulate reasonable rules and regulations for management systems.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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