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# Expert consensus on the metaverse in medicine

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ABSTRACT

*Background:* Recently, Professor Chunxue Bai and colleagues have proposed a definition of the Metaverse in Medicine as the medical Internet of Things (MIoT) facilitated using AR and/or VR glasses.
*Methods:* A multi-disciplinary panel of doctors and IT experts from Asia, the United States, and Europe analyzed published articles regarding expert consensus on the Medical Internet of Things, with reference to study results in the field of metaverse technology.
*Findings:* It is feasible to implement the three basic functions of the MIoT, namely, comprehensive perception, reliable transmission, and intelligent processing, by applying a metaverse platform, which is composed of AR and VR glasses and the MIoT system, and integrated with the technologies of holographic construction, holographic emulation, virtuality-reality integration, and virtuality-reality interconnection. In other words, through interactions between virtual and real cloud experts and terminal doctors, we will be able to carry out medical education, science popularization, consultation, graded diagnosis and treatment, clinical research, and even comprehensive healthcare in the metaverse. The interaction between virtual and real cloud experts and terminal users (including terminal doctors, patients, and even their family members) could also facilitate different medical services, such as disease prevention, healthcare, physical examination, diagnosis and treatment of diseases, rehabilitation, management of chronic diseases, in-home care, first aid, outpatient attendance, consultation, etc. In addition, it is noteworthy that security is a prerequisite for the Metaverse in Medicine, and a reliable security system is the foundation to ensure the normal operation of such a platform.

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*Conclusion:* The application of a Cloud Plus Terminal platform could enable interaction between virtual and real cloud experts and terminal doctors, in order to realize medical education, science popularization, consultation, graded diagnosis and treatment, clinical research, and even comprehensive healthcare in the metaverse.


## 1. Introduction

Since 2021, the concept of the metaverse has been widely discussed. It refers to the internet accessed via virtual reality (VR) and augmented reality (AR) glasses, and is considered to be the next-generation mobile computing platform that will be widely used in the future.[1] Others believe that the metaverse is a ternary digital world established on the basis of digital technology integrating the virtual and the real worlds, which people enter with digital identities. The idea originated from the novel *True Names* by Professor Vernor Vinge, an American mathematician. In this story, published in 1981, the author creatively conceived a virtual world that enters and obtains sensory experience through a brain-computer interface. Later, in 1992, the term "metaverse" was coined by American science-fiction writer Neal Stephenson in his novel *Snow Crash*, in which the characters explore an internet world parallel to the real world, using digital avatars of themselves for perception and interaction.[2–3]

The rise of the metaverse has brought infinite possibilities to all types of sectors and occupations, such as video game production, leisure, and entertainment. Museum exhibitions have evolved with diverse digital technologies,[4] and new metaverse sales models have emerged from traditional retail.[5] Some researchers have studied the art community of the 3D virtual world. Concerning social media, on October 28th, 2021, Mark Zuckerberg announced that Facebook had changed its name to "Meta" to align the company with its focus on new computing technologies and the metaverse.[6] Others seek to understand how journalism is practiced in the metaverse.[7–8]

Recently, Bai and colleagues proposed the metaverse in medicine,[9] and suggested naming 2022 as the Year of the Metaverse in Medicine. The expert group further discussed the definition of the metaverse in the medical context, and its concept and application scenarios, as well as its clinical importance. It is expected that this new concept will contribute to improving comprehensive healthcare as well as prevention and treatment of diseases, and to upgrading the current diagnosis and treatment model - which varies between doctors and hospitals, creating uneven standards akin to production in handicraft workshops (referred to as the "handicraft workshop model" hereinafter) - to a modern assembly-line model that meets national and even international standards.

## 2. The concept of a metaverse and its possible applications in medicine

To understand the validity and feasibility of applying the metaverse in medicine, it is necessary to first understand its concept. The metaverse is the internet accessed via VR and AR glasses,[1] which has been increasingly acknowledged, and is considered as a manifestation of next-generation mobile computing platforms. Similarly, the Metaverse in Medicine can be defined as the medical Internet of Things (MIoT) facilitated using AR and VR glasses.

The current practice also implies the wide scope of applications of the metaverse, including general settings, such as social activities, e-commerce, education, gaming, and payments,[10] and special fields, such as medicine.[9] In fact, many of the internet-based applications that we are familiar with already have a presence in the metaverse. Looking back through history, the personal computer (PC), undoubtedly the mainstream computing platform of the 1990s, was applied in telemedicine.[11] Later, we witnessed the rise of the mobile phone. This has gradually replaced the PC,[12] and has been integrated into the internet or the Internet of Things (IoT).[13]

Today, many people believe that VR and AR glasses will become an important part of next-generation computing platforms. Internet applications will also undergo updates and iterative development along with the replacement of computing platforms. For instance, where previously we had internet-based instant messaging software on PCs, including QQ and Microsoft Service Network (MSN), for social exchanges, nowadays we use WeChat on our mobile phones.[14–15,16] Similarly, significant changes have happened to e-commerce, as new applications emerge in the smartphone era, such as smoking consumption intervention.[17] By deploying the precise positioning function of smartphones, Local Life is capable of recommending high-quality services within a distance of 3 km from users, something that was impossible in the PC era. It creates a brand-new user experience based on the new platform, which can also be applied for the prevention and control of COVID-19.[18]

Why is the concept of metaverse so widely accepted, and why has stress been laid on its application in the medical field? Because VR and AR technologies will enable everyone to use digital avatars for face-to-face communication in the virtual world. Technological advances have been transforming e-commerce, and may lead to changes in the applications for comprehensive healthcare and medical services. In order to understand the influence of VR and AR glasses on internet-based applications, we need to analyze the essence of the technologies adopted by these glasses, which is, to display core interactions of the new platform. In the past, the two-dimensional display interface determined that all applications were based on child windows, whether on PCs or mobile phones. This was the reason that the Microsoft operating system was named "Windows". The user interaction was completed through mouse clicks and drags, whereas VR and AR glasses can provide a three-dimensional interface for display and interaction, enabling us to become immersed in a virtual world of information. Imagine that a virtual person in front of us is having a conversation with us, or that there is a virtual shelf filled with all sorts of goods next to us. In this three-dimensional space, interaction can be through body movements, language, gestures, and gaze.[19] The three-dimensional interface for display and interaction is the fundamental setting in such applications, and the superstructure will undoubtedly undergo revolutionary changes, including drastic expansion of its application scenarios in medicine and comprehensive healthcare.[19]

The replacement of the computing platform will lead to tremendous changes in the entire internet industry, including hardware, software, operating systems, and even the industry structure.[19] Transformation is also expected to take place in the medical field.[9] Similarly, to the revolution from PC to smartphone, today's technological advances will result in the rise of new key players in different areas, including in medicine and the healthcare industry.

## 3. The medical Internet of Things (MIoT) facilitates important application scenarios for the metaverse

### 3.1. The MIoT can assist in the practice of P4 medicine

The term “the Internet of Things” (IoT), coined by Professor Kevin Ashton at Massachusetts Institute of Technology (MIT) in 1999,[20] originally referred to the application of radio-frequency identification (RFID) technology and devices, combined with the Internet, using agreed communication protocols to intelligently manage objects.

Since 2008, Bai et al. have been developing an innovative wireless spirometer integrated with a mobile phone, which was featured in an article published by the American Thoracic Society (ATS) in ATS NEWS (Vol. 35, No. 7/8).[21] Being among the first to introduce the Medical Internet of Things in China and worldwide, Bai and his team also built the world’s first MIoT-based home tele-monitoring and management platform for obstructive sleep apnea-hypopnea syndrome (OSAHS).[22] He has served as the Editor of *Practical Medical Internet of Things*[23] and *Guidelines on Applying Medical Internet of Things for the Graded Diagnosis and Treatment*[24] (People’s Medical Publishing House), *Medical Internet of Things* (Science Press),[25] and together with Christoph Thüemmler, as author of *Health 4.0* (Springer Publishing Company).[26] Although the MIoT is still at an early stage of development, it is showing great potential, and has already been applied in many medical fields. Today, the MIoT has become synonymous with a network of physical objects across the internet,[13] integrated with both hardware and software, for the purpose of perception, transmission, and intelligent processing in a variety of medical application scenarios. We are witnessing significant growth in the application of the MIoT for clinical purposes along with the diverse extension of embedded devices that integrate the virtual world (information) and the real world (objects), enabling us to create a huge healthcare market that benefits the patients.

The MIoT has become an increasingly acknowledged concept in China and abroad. In a recent systematic mapping study by Sadoughi et al.,[27] articles published between 2000 and 2018 in major online scientific databases, including IEEE Xplore, Web of Science, Scopus, and PubMed, were screened, and a total of 3679 papers related to the IoT in medicine were reviewed, amongst which 89 papers were finally selected based on specific inclusion/exclusion criteria. China, India, and the United States were shown to be the top countries in knowledge production regarding the MIoT. In addition, the ambiguity of the terms assigned to the IoT, namely system, platform, device, tool, etc., and their interchangeable uses in the literature, suggested that a taxonomic study was required to investigate the precise definitions of these terms. The papers also demonstrated the extensive influence and recognition that the MIoT has gained.

### 3.2. The MIoT can help improve the quality of healthcare

In the *Strategy for American Innovation* (2014),[28] IT adoption in medicine and healthcare was considered as one of the 6 priority fields for innovation in the USA. The Asthma Health App (AHA) was designed to conduct large-scale health research and provide real-time air pollution monitoring. Based on data analysis of the users’ electronic asthma diary, this app can predict acute attacks, contributing to the primary and secondary prevention of the disease.[29] As part of the Leading Age Center for Aging Services Technologies (CAST), Intel developed wireless sensor networks (WSNs) for in-home healthcare solutions.[30] Sensing devices embedded in objects such as shoes, furniture, and home appliances, could make it possible for the elderly and those with disabilities to continue to live independently at home, while medical staff and social workers could also provide assistance when necessary. Sponsored by the Defense Advanced Research Projects Agency (DARPA), MIT conducted research on ultra-low-power WSNs, while Auburn University devoted considerable effort to studying self-organizing sensor networks,[31] and completed the development of some experimental systems. Scientists at the University of Rochester built a smart medical room equipped with wireless sensors in which dust was used to measure important signs of the occupant (such as blood pressure, pulse, and respiration), sleeping position, and 24-hour daily activities.[32]

The AMON project,[33] funded by the EU IST FP5 program with the participation of several research institutes, aimed to develop a wearable tele-monitoring and alert system. The wrist-worn device integrated a system that included continuous collection and evaluation of multiple vital parameters, intelligent detection and management of a medical emergency, and a cellular connection to a medical center. STMicroelectronics and Mayo Clinic jointly developed an innovative telemedicine platform for the management of chronic cardiovascular diseases.[34] Not only did it perform long-term monitoring without interfering with the patient’s everyday activities, but it also provided appropriate treatment options based on specific clinical information and physiological parameters. A study from the University of Malaga and the University of Almeria proposed a real-time WSN with a specially designed pulse oximeter, using software installed on a PC or PDA to monitor the pulse and peripheral oxygen saturation ($SpO_2$) of different patients at the same time, achieving great simplicity at a low cost.[35]

Japan, with its solid network and technological foundation for the IoT, has also been increasing investment in the sector of medical informatization. For example, Toshiba developed an artificial intelligence (AI) system composed of wrist-worn wearable sensors and a PDA that could monitor and analyze the user’s health, daily activities, and personal habits.[36] By offering reminders and advice on a healthy diet and regular exercise, tailored to specific individuals, the AI played a key role in making behavioral changes and reducing the risk of lifestyle-related diseases. Based on the wrist movement, pulse rate, and electrodermal activity, the software reached 90% accuracy in detecting the user’s activities, such as eating and taking exercise.

China has been researching the application of the MIoT in clinical practice since 2008, including the AI-assisted early diagnosis of lung cancer. Researchers created a database for the training and validation of a multimodal deep learning model, and established a cloud computing system based on a graphics processing unit (GPU) for parallel processing, with access to electronic medical records (EMRs) and the picture archiving and communication system (PACS). By developing PNapp5A, an IoT-assisted application that adopted a 5-step assessment of pulmonary nodules, they managed to enhance the early diagnosis of pulmonary nodules using big data-driven management technologies.[37] The team also took the initiative to develop the *Chinese Expert Consensus on the Diagnosis and Treatment of Pulmonary Nodules*,[38–40] and promoted the MIoT platform in around 900 hospitals where the Chinese Alliance Against Lung Cancer (CAALC) centers and sub-centers are located. According to Zhongshan Hospital, Fudan University, a total of 16,417 cases of pulmonary nodules underwent surgical treatment from 2014 to 2019, amongst which 9980 cases (60.8%) of early-stage lung cancers were reported. The patients’ average age declined from 63 to 50 over the 6 years.[41] Based on his experience of accurately diagnosing pulmonary nodules smaller than 10 mm with AI assistance, Professor Chunxue Bai proposed the concept of a human–computer multidisciplinary team (MDT), aiming for consultation on the basis of human–computer communication and interaction. Trials have been carried out with outpatient services adopting a human–computer MDT, providing comprehensive diagnosis and treatment plans that combine experts' suggestions and AI results. This new approach facilitates the standardization of early-stage lung cancer screening, diagnosis, and treatment for difficult cases with indeterminate pulmonary nodules.[40]

Another clinical application in China is the AI-assisted diagnosis and treatment of viral pneumonia. A precisely designed intelligent system with access to the relevant clinical information and CT imaging can be used for the screening and management of suspected cases and indeterminate cases. For example, a mobile phone-based tool called nCapp was developed for the diagnosis and treatment of COVID-19, and was recommended by the ATS.[42] Furthermore, China is working on applying the MIoT for the management of chronic diseases, such as chronic obstructive pulmonary disease (COPD) and asthma. By leveraging big data training and the MIoT embedded with a portable spirometer, it is feasible to provide accurate and personalized guidance and plans for the daily life activities of each patient, in order to relieve the condition, improve their quality of life, and prevent acute exacerbations of the disease.[43]

### 3.3. Importance of the MIoT

China has been facing health resource disparities between regions and hospitals. Small rural hospitals tend to have scant access to high-end medical devices ("insufficient equipment coverage"), the local doctors have limited technical experience ("insufficient technical competence"), and the patients often have poor recognition of medical care ("insufficient patient satisfaction"). Because of these "Three Deficiencies", many patients prefer to go to large hospitals and consult prominent doctors for better diagnosis and treatment, resulting in difficulties in registration and hospitalization, which are referred to as the "Two Difficulties".[23–25,44] The influx of rural patients into city hospitals also restricts the time that each expert can spend with each patient, leading to limitations in distributing services in prevention, healthcare, disease management, and rehabilitation, which we refer to as the "Four Limitations". To address these issues, we proposed utilizing the MIoT and suggested using the three basic functions of the MIoT, comprehensive perception, reliable transmission, and intelligent processing, to assist doctors in clinical practice,[23–25] which have been successfully applied in many cases.

Furthermore, due to the increasing demand for healthcare and the large number of practitioners involved, it is costly to provide satisfactory and accessible healthcare services for patients. The IoT, which combines communication technologies with intelligent mobile devices, is able to play a crucial role in addressing this issue. As one of the most frequently deployed innovations in the e-health sector, the MIoT has been redistributing healthcare services from medical centers to homes and the workplace.[45] Since 2018, knowledge production in the MIoT and relevant fields has significantly increased. Additionally, the COVID-19 pandemic has highlighted the need for the provision of healthcare services to patients at home, which is also considered as one of the goals of e-health, and especially of the MIoT.[46] On the one hand, IoT applications are usually developed to save costs, offer greater accessibility for patients at home, and encourage patient empowerment, which serves to promote healthcare and personal well-being. On the other hand, the Digital Twin model, introduced in 2002 by Grieves as a new standard for Industry 4.0,[47] makes it possible for the integration of VR and AR technologies into the MIoT, and for accelerating the transformation into clinical applications with high efficiency (IEEE - Digital Twin: Enabling Technologies, Challenges and Open Research). Nevertheless, as an emerging discipline in applied science, the MIoT is faced with a series of challenges like any other new medical technology, especially in terms of medical supervision, medical insurance, and the digital divide, all of which need to be validated and addressed by large scale clinical application and promotion in the near future.[48]

Bai et al. expect that the MIoT will develop into a school of thought,[9] and become a powerful medical tool, since it has the potential to realize "simplification of complex problems, digitalization of simple problems, programming of digital problems, and systematization of programming problems". The ultimate goal is to upgrade China's medicine and healthcare from the current model, which varies between doctors and hospitals and has uneven service levels, to a modern assembly-line model that meets national and even international standards, thus fulfilling our vision: wise doctors treat patients before onset of diseases, great doctors benefit the general public.

### 3.4. Limitations of the MIoT

eAccording to the present MIoT theory, it is feasible to overcome the "Three Insufficiencies", "Two Difficulties", and "Four Limitations", and realize efficient and accurate graded diagnosis and treatment through the linkage between the doctors in large hospitals (cloud experts) and the doctors in small and rural hospitals (terminal doctors). Continuous research and development of related technologies will also contribute to improving the graded diagnosis and treatment.[27,37] However, the following issues remain in clinical practice: (1) The cloud experts are not available to participate in science popularization and professional lectures as if they were present at all times and in all settings. (2) The cloud experts are not available to provide guidance for the terminal doctors on the diagnosis and treatment at all times and in all settings. (3) In clinical trials, the major researchers are not available to supervise the research and instruct the team at all times and in all settings. (4) Due to the lack of real-time quality control at all times and in all settings, non-standard diagnosis and treatment, the so-called "handicraft workshop model", still exists to a considerable degree.

The real cause lies in the incompatibility between the service provided by the cloud experts and the needs in the real world, the inability of the cloud experts to attend to the general public at all times and in all settings, and the limitations of the internet technology itself. Therefore, it is necessary to develop an optimized digital platform in order to tackle the limitations of the MIoT, especially concerning communication and interaction between the human and the computer, and the integration and interconnection between the virtual and the real worlds. It is gratifying that the emergence of the metaverse has provided a possible solution for all these problems, which also serves as the foundation for the proposal and development of the Metaverse in Medicine.[26–27,49–50]

## 4. The metaverse provides technical support to maximize the value of the MIoT

### 4.1. The prototype of the Metaverse in Medicine implies prospects for its development

The Metaverse in Medicine, which is defined as the medical Internet of Things accessed via AR and/or VR glasses, indicates the importance of AR and VR technologies. We have conducted extensive research on the MIoT,[50] which serves as the foundation for establishing the Metaverse in Medicine. For example, we focused on the research and development of the BRM all-in-one machine, which can be seen as the prototype of the Metaverse in Medicine (Fig. 1). More recently, we have initiated a related study to further explore how to implement the Metaverse in Medicine by applying holographic construction and emulation, and virtuality-

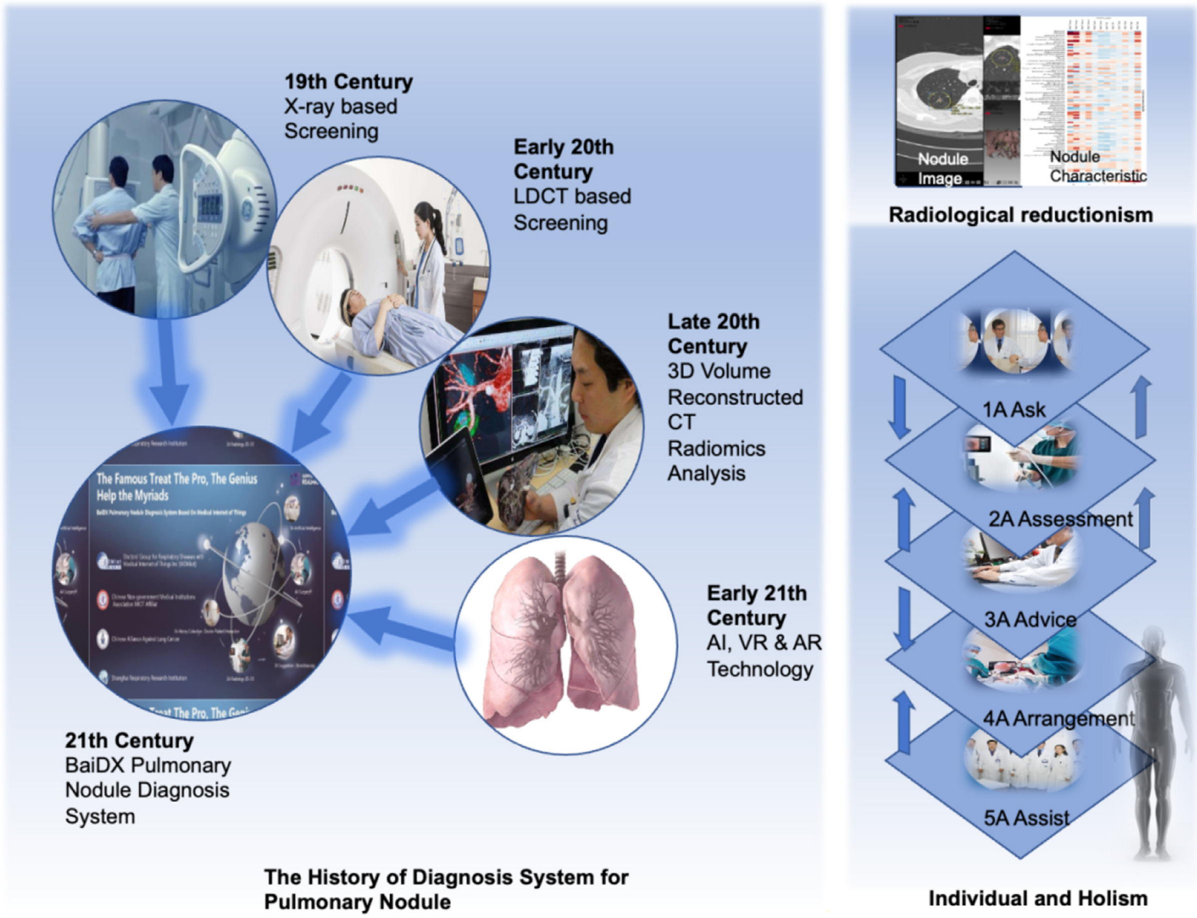


**Fig. 1.** Application of the BRM all-in-one machine and progress in R&D of the holographic system for the early diagnosis of pulmonary nodules and lung cancer screening.

reality integration and interconnection (Fig. 2). In order to put it into better practice, we suggest to broaden the concept by adding comprehensive perception to the holographic construction, adding intelligent processing to the holographic emulation, adding quality control to the virtuality-reality integration, and adding human–computer integration to the virtuality-reality interconnection, thus realizing "simplification of complex problems, digitalization of simple problems, programming of digital problems, and systematization of programming problems".[50] This approach can overcome the obstacle that internet-based healthcare and telemedicine platforms hardly play an active role in county hospitals, especially those in rural villages and towns. Moreover, it will facilitate graded diagnosis and treatment, and contribute to transforming the current handicraft workshop model, which varies between doctors and hospitals with uneven levels, into a modern assembly-line model that meets national and even international standards.

### *4.2. Holographic construction and holographic emulation will further improve the MIoT*

Holographic construction, also known as multi-dimensional or stereoscopic information, refers to a model incorporating all the information of a certain system, which has been collected and compiled from multiple channels, perspectives, and positions.[51] The data in the system should include not only specific information on the working status of each device, data transmission, and system interaction, but also data on the factors that influence the operation of the system, such as the natural and social environment in which the system is located. At present, VR home inspection and shop inspection are applications in the holographic construction.[52–53] Holographic emulation is a new feature that vastly reduces iteration time when developing holographic applications in Unity. Studies have shown that developers creating applications for Microsoft HoloLens will immediately benefit from being able to prototype, debug, and iterate design directly from the Unity Editor without getting bogged down by long build and deploy times.[54] Although the current research is not applied to medicine, our preliminary study suggests that holographic emulation is a promising technique for the medical field because it can address the issue of how to enable experts to provide services at all times and in all settings, which cannot be solved by the MIoT.

How can we fully apply holographic construction and holographic emulation in medical practice? The first step is to understand the pathological, pathophysiological, or biochemical changes caused by different diseases, in order to strictly implement P4 medicine (predictive, preventive, personalized, and participatory). To solve practical problems, we suggest to introduce the concept of comprehensive perception in the holographic construction and emulation of the metaverse, since current studies have confirmed that it can meet the requirements of the Metaverse in Medicine. A solid technological foundation has already been laid in medicine, including the use of a variety of sensors applying photosensitive, gas sensitive, force sensitive, sound sensitive, and radiation sensitive components, biochemical examinations to test liver and kidney function, electrocardiography (ECG), ultrasound, computed tomography (CT), positron emission tomography

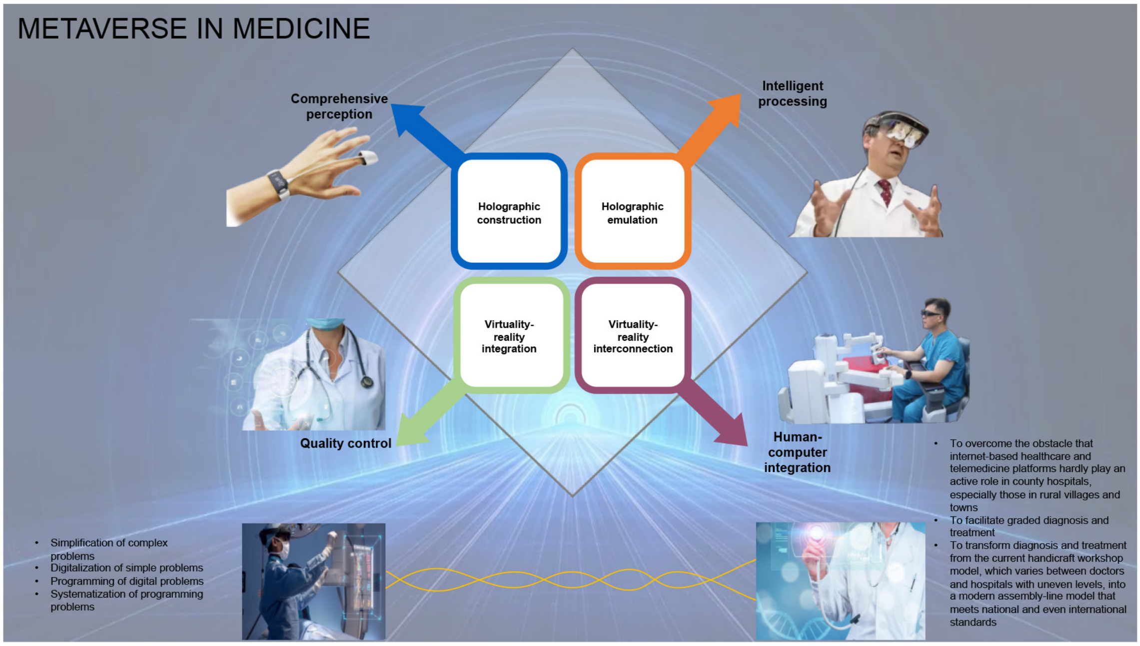


**Fig. 2.** Flowchart of implementing the Metaverse in Medicine by applying holographic construction and emulation, and virtuality-reality integration and interconnection.

– computed tomography (PET/CT), the spirometer, and the pulse oximeter. These technologies enable us to monitor the physiological, pathophysiological, and biochemical changes in the body at all times and in all settings (or partly), and create a complete infographic of the condition of health, sub-health, or disease. Consequently, doctors and patients can enter the metaverse with their own digital twin, and practice metaverse medicine through virtuality-reality interconnection. Only when the metaverse creates an immersive experience, in which people cannot distinguish the virtual world from the real one, will it attract the participation of patients and doctors.[55]

The Metaverse in Medicine may also be applied to improve the efficiency of education and training, since it can address the issues that the cloud experts are not available to participate in science popularization and professional lectures, or to provide guidance for the terminal doctors on diagnosis and treatment as if they were present at all times and in all settings. For instance, we used the BRM all-in-one machine adopting holographic emulation technology to show students the mechanism of cigarette smoking-induced lung cancer.[56] This pioneering pedagogical practice produced sensational effects because the students observed in an immersive way the alveolar damage caused by smoking and its relationship with the onset of lung cancer (Fig. 3). Furthermore, we can also train students to quickly master various therapeutic techniques as if they were present in clinical practice, such as magnetic navigation, a difficult technique to apply in surgeries with respiratory endoscopy. If holographic emulation is used in teaching and clinical practice, it will undoubtedly help us to achieve better results with less effort.[57]

The research and practice of the Metaverse in Medicine can be difficult, since the body structure, etiology, pathological and pathophysiological changes, as well as the pharmacodynamics in different patients are extremely complicated. However, based on the successful cases of applying the concept of the Metaverse in Medicine in the diagnosis and treatment of pulmonary nodules, we estimate that solutions and principles can be found through careful classification of the diseases and extension of the research on applying the metaverse in the diagnosis and treatment of diseases to different categories. In other words, we should develop and follow the consensus guidelines to "simplify complex problems".[50] After working out a solution that combines comprehensive perception with holographic construction, the information required for the holographic construction will be transmitted to the "Metaverse in Medicine Cloud", in preparation for the next step, holographic emulation plus intelligent processing, and eventually transforming the real world through the virtual one. Once all these issues are settled, we will be able to leverage emulation technology in the virtual world to seek optimal solutions for the problems in reality, and map it to the real world through virtuality-reality integration, so that the virtual and the real experts provide guidance for medical practice in the real world.

### *4.3. Virtuality-reality integration and interconnection can overcome the limitations of the MIoT*

To maximize the value of the MIoT in solving problems for patients, it is important to provide high-quality assistance in dealing with all kinds of issues in clinical practice. This is exactly the advantage of the Metaverse in Medicine. In addition to "digitalizing simple problems", which is already made possible by using the MIoT, the Metaverse in Medicine provides intelligent diagnosis or robotic assistance in treatment (such as in surgeries), enabling all students to have access to hands-on practice to gain experience, and successfully bridging the gap between education and practice.[58] Our previous studies have shown that it is feasible to monitor the pathophysiological parameters of diseases with MIoT-connected sensors, and assist clinical diagnosis and treatment based on intelligent processing of the data. For example, CT images for early-stage lung cancer screening have been transmitted to a cloud computer for intelligent processing to obtain assistance in diagnosis and differential diagnosis.[59] The same approach can be adopted in the Metaverse in Medicine because it is the MIoT facilitated using AR glasses.

The incorporation of AR glasses into the MIoT takes it to the next level, virtuality-reality integration. The cloud experts in both the virtual and the real worlds will guide the terminal doctors at all

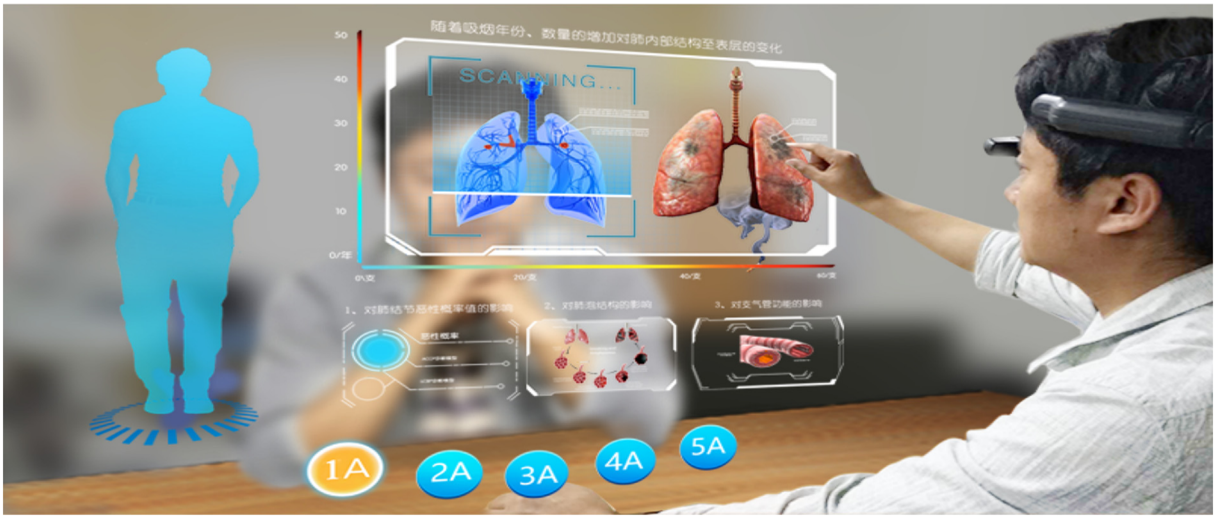


**Fig. 3.** The BRM all-in-one machine adopting holographic emulation technology vividly demonstrates the mechanism of cigarette smoking-induced lung cancer, the alveolar damage caused by smoking, and its relationship with the onset of lung cancer.

times and in all settings, transforming the diagnosis and treatment from the current handicraft workshop model to a modern assembly-line model characterized by homogenous service levels that meet national and even international standards. The virtuality-reality integration in the Metaverse in Medicine will effectively strengthen the linkage between the participants (doctors and patients), the real environment (devices) and the virtual environment (virtual doctors, patients, and devices).[60] The ultimate goal is to create a natural, immersive environment, and integrate virtuality into reality to provide medical services based on human–computer linkage.[61] High precision positioning, virtuality-reality integrated environment presentation, optical displays, and multi-sensory interaction are some of the key technologies required to achieve virtuality-reality integration.[62] Additionally, the diverse functions of the MIoT, such as intelligent diagnosis and treatment, disease management, and especially quality control, should also be shown on AR glasses. Therefore, it is crucial to design and produce high-end devices, make elaborate plans, organize education and trainings, and develop innovative techniques for quality control.

In an effort to put the Metaverse in Medicine into full practice, not only should the MIoT devices be taken into consideration, but the practitioners at grassroots level and specialist doctors should also be acquainted with the relevant knowledge and skills, and close collaboration between the cloud experts, the terminal doctors, and the patients will be required throughout the practice. In addition to general trainings, quality control in compliance with international standards is essential in the clinical application of the metaverse. (The App developed based on the Metaverse in Medicine will provide assistance in the quality control of the MIoT.) For example, in the assessment of pulmonary nodules, integration of experts (in reality) and robots (in virtuality, equipped with an AI system) ensured that the diagnostic results reached high sensitivity and specificity. In order to conduct strict quality control, we should train the robots with deep learning, and incorporate the consensus guidelines.[63] Currently, quality control cannot be carried out automatically at all times and in all settings, while the Metaverse in Medicine can overcome these disadvantages through virtuality-reality interconnection and human–computer integration between the humanoid robots and the cloud experts, achieving better results with less effort in quality control.

The combination between virtuality-reality interconnection and human–computer integration is the most important and valuable feature of the Metaverse in Medicine in clinical practice. In fact, technologies for virtuality-reality interconnection are quite mature, but excellent diagnosis and treatment results are not possible without human–computer integration. In theory, human–computer integration refers to a new form of intelligence generated by the interaction of man, computer, and system environment. In contrast to human intelligence and artificial intelligence, the new generation of intelligent system has both physical and biological properties.[64] Human-computer interaction mainly involves physiological and psychological sides of ergonomics that are not dominated by the brain, while human–computer integrated intelligence focuses on the intelligence dominated by the brain combined with the "computer". From a medical perspective, this combination, or "human-computer integration", refers to the joint effort of the cloud experts and the robots in communicating with each other to solve medical problems. We suggested to combine virtuality-reality interconnection and human–computer integration by programming, in order to "systematize the problems", and proposed the concept of "human–computer MDT",[50] adopting programmed digital technology to facilitate virtuality-reality interconnection. The study results of our clinical application over the 3 years have indicated that human–computer MDT is a perfect manifestation of the clinical value of the Metaverse in Medicine, since it significantly improves the sensitivity and specificity in pulmonary nodule assessment. It is believed that this approach can also be adopted in other application scenarios, such as disease prevention, healthcare, self-care, and geriatric nursing, so that the virtual and the real cloud experts provide guidance for the terminal doctors to implement diagnosis and treatment in line with the consensus guidelines. For example, during robotic surgery, the cloud experts can guide a distant robot to perform surgical treatment on the patient.

## 5. Prospects

This study shows that conditions are mature for the establishment of the Metaverse in Medicine, and the experts reached a consensus on how to develop it to better serve medicine and comprehensive healthcare. By applying the Cloud Plus Terminal platform, integrated with AR and VR glasses and the medical Internet of Things, the virtual and the real cloud experts and terminal doctors were able to communicate and interact in the metaverse for medical education, science popularization, consultation, graded diagnosis and treatment, and clinical research. Along with its development, the application of the Metaverse in Medicine could expand into comprehensive healthcare, not only enabling the virtual and the real cloud experts and terminal users (including terminal doctors, patients, and even their family members) to interact, but also facilitating different medical services, such as disease prevention, healthcare, physical examination, diagnosis and treatment of diseases, rehabilitation, management of chronic diseases, in-home care, first aid, and metaverse-assisted outpatient attendance and consultation, etc.

Major clinical and non-clinical application scenarios of the Metaverse in Medicine include: (1) research, (2) development of computer software, (3) consulting, (4) science popularization, (5) education and training, (6) clinical research (RCT, RWS, etc.), (7) healthcare, (8) physical examination, (9) self-care and geriatric nursing, (10) diagnosis and treatment of diseases, (11) drug and device therapy, (12) surgical treatment, (13) hospital management, (14) pharmacy, (15) quality control in medicine, (16) disease prevention, (17) insurance, (18) meeting, etc. Although trials have only been carried out in a few scenarios at present, we believe that it is just a matter of time before the metaverse is perfectly applied in all these scenarios, with the solid technical foundation of the MIoT and the metaverse. If we move with the times and work against the clock, we will be able to accelerate progress towards achieving our targets.

Leveraging the high technologies of the Metaverse in Medicine in these application scenarios will also contribute to fulfilling our vision of benefiting the general public. Moreover, it is noteworthy that security is a prerequisite of the Metaverse in Medicine, and a reliable security system is the foundation to ensure the normal operation of such a platform. Availability, confidentiality, integrity, and controllability should be fully considered in the design of a comprehensive security system to ensure physical security, system security, operational security, and management security.

## Author contributions

All the authors make a substantial contribution to this manuscript. DY, ZJ, CP, NC and CB participated in drafting the manuscript. DY, JZ and CB wrote the main manuscript. All the authors discussed the results and implication on the manuscript at all stages.

## 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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## Availability of data and material

All relevant data and material are presented in the main paper.

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## Consent for publication

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