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THE ETHICAL RISKS AND REGULATIONS OF MEDICAL DIGITAL TWIN TECHNOLOGY

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Abstract: Medical digital twin technology has shown tremendous potential in personalized medicine, disease prevention and treatment optimization through real-time monitoring, simulation and prediction of individual health conditions by creating virtual models of patients. However, with the rapid development of this technology, its potential ethical issues have also attracted widespread attention. Firstly, medical digital twin technology involves collecting and processing a large amount of personal health data, and ensuring the privacy and security of this data becomes the primary concern. Secondly, the biases and unreliability generated by big data algorithms during the operation of the technology also need to be considered. Lastly, the digital gap and fairness issues generated by medical digital twin technology should not be overlooked. Therefore, in response to these ethical challenges, proposing corresponding ethical regulations becomes necessary, promoting the application of digital twin technology to enhance medical quality without infringing on patients´ legitimate rights and interests, and promoting fairness and justice in the medical field.

Keywords: medical digital twin technology, ethical risks, ethical regulations

Riesgos éticos y normativa de la tecnología médica de gemelos digitales

Resumen: La tecnología médica de gemelos digitales ha demostrado un enorme potencial en la medicina personalizada, la prevención de enfermedades, la optimización del tratamiento a través de la monitorización en tiempo real, la simulación y la predicción de las condiciones de salud individuales mediante la creación de modelos virtuales de pacientes. Sin embargo, con el rápido desarrollo de esta tecnología, sus posibles problemas éticos también han atraído una amplia atención. En primer lugar, la tecnología de gemelos digitales médicos implica la recopilación y el procesamiento de una gran cantidad de datos personales de salud, por lo que garantizar la privacidad y la seguridad de estos datos se convierte en la principal preocupación. En segundo lugar, también hay que tener en cuenta los sesgos y la falta de fiabilidad que generan los algoritmos de big data durante el funcionamiento de la tecnología. Por último, no deben pasarse por alto la brecha digital y los problemas de equidad generados por la tecnología médica de gemelos digitales. Por lo tanto, en respuesta a estos desafíos éticos, se hace necesario proponer las regulaciones éticas correspondientes, promoviendo la aplicación de la tecnología de gemelos digitales para mejorar la calidad médica sin infringir los derechos e intereses legítimos de los pacientes, promoviendo la equidad y la justicia en el ámbito médico.

Palabras clave: tecnología médica de gemelos digitales, riesgos éticos, normativa ética

Os riscos éticos e regulamentação da tecnologia de gêmeos digitais na medicina

Abstract: Tecnologia de gêmeos digitais na medicina tem demonstrado um potencial enorme na medicina personalizadas, prevenção de doenças e otimização de tratamentos através de monitoração em tempo real, simulação e predição de condições de saúde individuais por meio da criação de modelos virtuais de pacientes. Entretanto, com o rápido desenvolvimento dessa tecnologia, seus potenciais problemas éticos tem também atraído ampla atenção. Primeiramente, tecnologia de gêmeos digitais em medicina envolve coletar e processar uma grande quantidade de dados de saúde pessoa e garantir a privacidade e segurança desses dados torna-se a principal preocupação. Em segundo lugar, os viéses e falta de confiabilidade gerados por algoritmos de *big data* durante a operação da tecnologia necessitam ser considerados. Finalmente, a lacuna digital e as questões de eqüidade geradas por tecnologias de gêmeos digitais em medicina não deve ser negligenciada. Portanto, em resposta a esses desafios éticos, torna-se necessário propor regulações éticas correspondentes, promovendo a aplicação de tecnologia de gêmeos digitais para melhorar a qualidade médica sem infringir os legítimos direitos e interesses dos pacientes, e promovendo eqüidade e justiça no campo médico.

Palavras-chave: tecnologia de gêmeos digitais em medicina, riscos éticos, regulações éticas

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1. Introduction

At present, the rapid development of artificial intelligence technology is leading the intelligent transformation of society, turning the beautiful prophecy of a "digitally intelligent survival state" into a readily available reality. Digital twin technology, as a representative product of this trend, is increasingly used as a basis for scientific decision-making and practice in various fields such as industry, transportation, agriculture, and healthcare. Digital twin technology can improve production efficiency and enhance production levels by establishing industrial digital models, simulating manufacturing processes, and conducting predictive maintenance and preventive repairs on equipment. This technology can also optimize traffic systems and alleviate traffic pressure by establishing virtual traffic models and predicting traffic conditions. At the same time, it can simulate digital farming scenarios, accurately perceive agricultural production factors such as soil, farming equipment, and climate, and dynamically adjust farming processes to improve soil structure and crop quality.

The advancement of medical science is also closely related to technological development. The application of digital twin technology in the medical field can establish a virtual mapping of medical models and a real connection with patient entities, achieving a life-cycle coverage of prevention, treatment, and rehabilitation. Of course, while enjoying the benefits and convenience brought by the rapid development of medical digital technology, the ethical concerns it raises are also worth deep reflection and avoidance.

2. Medical Digital Twin Technology and Social Ethical Interests

The term "Digital Twin Technology (DT)" first emerged in the context of the digitization of 3D arterial models in 1994 and was included in the technology roadmap of the National Aeronautics and Space Administration (NASA) in 2010. However, the concept was utilized as early as the 1960s by radiologists and engineers at NASA. Radiologists employed simple model calculations to replicate the response of human tissues to radiation, while NASA engineers created systems on the ground that mirrored space systems*(1)*. The entities involved in medical digital twin technology include patient populations, hospital entities, healthcare personnel, medical equipment, data connection media, and virtual digital models*(2)*. By connecting the aforementioned entities, an individualized, lifelong patient digital twin model is ultimately constructed.

Medical digital twin technology applies digital twin technology to the medical field, creating a data model based on real patient information within a virtual medical environment, establishing a connection between the patient's data model and the physical patient, observing and analyzing the model's response to stimuli, such as the patient's feedback to new drugs or treatment plans, and providing medical guidance for prevention, treatment, and convalescence through the analysis of the patient's medical digital model. Should the potential and role of medical digital twin technology be harnessed effectively, it would bring profound value implications to human society.

Enhancing Patients' Understanding of Diseases. Medical digital twin technology can provide a broad and profound understanding of individual health conditions, playing a significant role in offering comprehensive medical protection. This technology integrates and analyzes data from various sources, including wearable devices, genetic information, and patients' medical examination reports*(3)*. This more comprehensive data integration allows doctors and patients to devise interventions and treatment measures based on individual circumstances, isolating potential health risks and ultimately improving patients' medical decision-making. The digital medical model of patients can provide real data feedback, and a robust digital infrastructure can also manage the vast flow of data.

For instance, a hospital's digital team, through digital twin technology and healthcare systems and equipment, has proposed an advanced digital medical decision-making model. This model can systematically evaluate current medical services and avoid potential medical risks, while also assisting hospitals in operating more efficiently. Moreover, medical digital twin technology also aids in tracking patients' longitudinal data, allowing healthcare providers the opportunity to analyze patients' real-time data over time. This longitudi-

nal analysis enhances physicians' insight into patient data, thereby providing personalized prevention, treatment, and prognostic care for patients.

Promoting the development of digital clinical trials and drugs. Medical digital twin technology surpasses traditional trial methods by using virtual digital patients, no longer relying on "humans" in physical entities for drug clinical trials. Instead, this technology is integrated throughout the trial process, including patient recruitment and sample testing. By providing insights and optimizing clinical design plans, it will transform drug trials and drug development in the clinical field*(4).* This can greatly reduce the harm and damage caused to the human body by clinical trials of drugs. Before a new drug or medical technology is introduced, it must undergo extensive animal testing and human clinical trials to test the drug or medical technology, which may harm the health of humans and animals. Moreover, the final development and application of clinical trials is a very time-consuming and complex process, with an average cycle of 6 to 15 years*(5).*

According to a data study in the United States, it takes nearly $2.6 billion to bring a new drug from research to final approval for market launch. What's more alarming is that about 85% of drug treatments fail in the early stages of clinical trials, with only a small number of fortunate drug trials reaching the later stages of clinical trials, which only means half the battle is won. In addition, some pharmaceutical companies in the United States spend nearly $6 billion annually on recruiting trial volunteers, and the number of people who meet the criteria and are willing to serve as volunteers is very small*(6).* Certainly, when there is a large amount of medical data available for statistical analysis and a plethora of experimental data to dissect, clinical simulation trials allow for the meticulous selection of samples for study. The introduction of this technology becomes extremely valuable when faced with limited medical data samples, and its reliability also greatly increases. In traditional clinical trials, it is challenging to address the diversity and variability of patient samples. For instance, a medical trial might involve implanting stents in patients to observe their recovery response post-implantation. Assuming the stents are implanted into digital patient models, this not only enhances the safety applied to patients but also reduces the cost of clinical trials. It is more conducive to ushering in a new era of clinical practice, bringing a brighter future for patients*(7).*

In the near future, it will be possible to collect and analyze trial data from a population of digital patients. By categorizing these digital populations based on various customized parameters such as gender, age, and genetic makeup, these "digital humans" will be able to fully play the role of a group sample, thereby significantly improving the precision of clinical trials for drugs and medical technologies.

Medical digital twin technology, by creating a virtual digital model of the patient, enables remote monitoring and treatment of the patient. This technology can almost be said to be an innovation in the way patients enjoy medical security services. Patients can use devices such as smart wristbands, motion locators, and smart blood glucose monitors to remotely connect the physical patient with the digital model through the network, thereby obtaining timely medical assistance and avoiding delays in treatment due to distance issues. Although remote consultation and treatment methods already exist, these are mostly suitable for the treatment of chronic and mild diseases.

However, the application of digital twin technology can assess the overall health condition of the patient through the patient's symptoms and the data feedback from the digital model, thereby providing more targeted treatment plans. In the future, this technology may also increase the possibility of remote treatment of acute and severe diseases, transmitting medical data from areas with fewer resources to medical institutions in areas with more abundant resources through secure channels, providing valuable medical advice to doctors, and creating more possibilities.

In terms of remote monitoring, digital twin technology can reduce the number of patient hospitalizations and readmissions. By closely monitoring the patient's physical condition at home or in non-emergency situations, it can detect early signs of disease outbreaks or prevent the occurrence of serious disease complications promptly.

This technology is also suitable for the transition from hospital to home, ensuring the continuity of treatment and care. Through video remote connections, patients can perform self-diagnosis of digital medical conditions, increasing the enjoyment of personal rights to life and health.

With the advancement of technology, the application prospects of digital twin technology in the medical field are broad. It not only brings more accurate health management and treatment plans for patients but also brings new opportunities driven by data to the medical industry. It is expected to achieve personalized medicine, improve treatment effects, and promote the innovative development of medical care. However, the ethical issues that may arise from the use of digital twin technology also need to be addressed and resolved.

3. The Ethical Risks of Medical Digital Twin Technology

Privacy and Autonomy in Patient Data Collection. Medical digital twin technology is still in its infancy, and the ethical guidelines and regulatory frameworks for this technology are not yet fully developed. However, the primary ethical requirement for digital twin technology in the medical field is the issue of privacy and autonomy. Unlike its applications in transportation, agriculture, and urban construction, digital twin technology in healthcare requires privacy information at the level of life due to its nature. In medical digital twin technology, the Internet of Things (IoT) collects patients' personally identifiable information, health data, genetic data, and other data involving patient privacy*(8)*. Once their data is collected, it may be stored and recorded for a long time, and to continuously update the patients' health data, patient information will also be continuously collected.

For example, a patient needs to take smart pills to measure biological data such as blood pressure and heart rate, or even invasive methods are required to collect patient data. In such cases, not only does the invasive act itself pose security risks, but there is also a tendency to infringe upon the patient's privacy-protected health data.

Thus, in the process of using medical digital twin technology, issues involving patient privacy rights become apparent in two aspects: First, the overscrutiny of patient information. When establishing a digital patient model to provide better personalized care plans for patients, it is necessary to obtain all of the patient's medical data. In this process, it is inevitable to involve the privacy that the patient wishes to protect, and the use of medical digital twin technology carries the risk of infringing on patient privacy. Second, the leakage of patient data by others. In medical digital twin technology, medical and technical entities involved may have access to patient information, and once patient data is over-scrutinized, it then faces the risk of being leaked. If this data is maliciously leaked or even maliciously obtained by third parties, it poses a greater challenge to the protection of patient privacy rights.

In medical digital twin technology, the rights to privacy and autonomy are also intertwined. The application of this technology brings significant benefits to both doctors and patients. Physicians can obtain a lot of data closely related to the patient's body through this technology, but over time, it may lead to healthcare workers and medical institutions becoming overly dependent on data for judgment, which can gradually weaken the autonomy of medical staff in assessing the patient's health condition. More importantly, as people alternate between the virtual and real worlds, it can create illusions that affect their judgment of their own body and the real world. In the clinical application of this technology, patients need to immerse themselves in the virtual experience of the "digital model" for a long time, which can also affect their perception and adaptation to the real world, posing potential psychological health risks for patients and even the crisis of disintegration of personality. In such circumstances, the autonomy of patients can be subtly weakened*(9)*. In addition, patients' level of awareness of medical digital twin technology is not high enough, which also affects the implementation of patients' autonomy rights.

Big data algorithms generate biases and unreliability. In this technology, the Internet of Things systems continuously establish training sets for patients' medical twin data, and the technology itself is also continuously iterating and updating

through algorithms, striving to provide patients with the "optimal" solution. However, whether the "optimal" determined by the technical algorithm is "truly optimal" is debatable, which involves the risky decision-making resulting from the black box of machine learning algorithms*(10)*. The algorithmic black box is considered to be a process where algorithm designers transform inputs into outputs in a non-transparent manner, while the internal working principles remain unknown. Thus, the use of the algorithmic black box represents the complexity of technology, and naturally, the risks it brings are self-evident*(11)*.

Even though that artificial intelligence technology has achieved many significant breakthroughs in various fields in recent years. For example, in 2014, Facebook's facial recognition system accuracy could reach 97.53%, almost at the human level. In the Image Net image database, the 2.99% error rate of artificial intelligence computational analysis is lower than the 5.1% error rate of humans. However, as artificial intelligence technology becomes more deeply integrated into multiple fields, the unreliability of its technology also gradually emerges. In many situations, there are computational errors, which are an inherent obstacle for any data science. Scientific and technological methods are more prone to errors than we might think, and the computation of biased data often leads to more problems.

Technologically intelligent algorithms are increasingly making important decisions for people's lives beyond human supervision. In medical digital twin technology, the virtual data of patients relies on algorithmic calculations, and there is a risk of whether the calculations between the data model and virtual data are unreliable. If only because the patient does not fully disclose their health data, it leads to the algorithm making incorrect judgments and treatment measures. And medical staff must rely on technological algorithms to build the patient's digital twin model and make medical diagnoses, then the unreliability of algorithmic data will also increase the health risks of patients. Even more, the pursuit of "black box" predictions and personalized care in medical digital twin technology can lead to new over-treatment*(12)*.

In the medical field, the opacity of algorithms is not limited to patients alone. When healthcare professionals rely on medical digital twin technology to provide treatment recommendations for patients, they may also be at risk due to a lack of understanding of the specific operational principles behind the technology. This uncertainty poses a potential threat to both physicians and patients. The evolution of medical digital twin technology not only aids healthcare providers in making more precise medical decisions but also involves issues of algorithmic recommendations in healthcare.

In the future, it is anticipated that individuals will have personalized digital medical models that can collect health data in real-time and potentially drive the development of individual health. For populations with specific healthcare needs, medical digital twin technology can identify their preferred health parameters, thereby assisting healthcare practitioners in devising personalized healthcare plans. This represents the positive impact of technological advancements on the healthcare industry. However, if the algorithms driving these technologies are biased, patients may be misled by the information and decisions recommended by the algorithms.

Taking medical healthcare products and devices as an example, these services may be provided to consumers under an unjust interest-driven mechanism, raising the question: Do these services truly align with the needs and desires of consumers?

The application of technology may also exacerbate the digital divide and issues of medical justice. The proliferation of medical digital twin technology may create disparities between individuals and regions. In this technology, raw data from patients, healthcare professionals, medical devices, and hospitals is key to constructing digital twin models. If these data are inaccessible to certain groups, a digital divide is created.

First, patients may not be able to access their health data, forming a digital divide at the technological access end. Second, even if patients can afford the cost of this technology, whether they can fully understand the treatment plan and the application of the technology, and whether these truly align with their interests, constitutes a digital divide at the technological usage end. Lastly, there

are also disparities in the degree of access to medical digital twin technology among patients from different regions, reflecting the urban-rural digital divide.

The digital divide issues we mention essentially involve the fairness of technology distribution. Patients not only need equal opportunities to access information but also need to involve the equity in the use of technology. The introduction and popularization of any new technology come with high costs. For instance, early artificial joint technologies used to treat severe joint diseases were very expensive, but as technology advanced and production scales expanded, costs significantly decreased. Medical digital twin technology may face a similar situation. If diagnostic and treatment services of this technology are not accessible to everyone who needs them, or if they are not covered by medical insurance, the popularization of this technology may exacerbate social inequality.

Moreover, the increase in medical costs associated with the technology may also affect the fairness of health welfare distribution. For most people, especially low-income groups, the wearable devices required for the use of this technology itself represent a significant expense. If the use of this technology becomes an exclusive service for the wealthy to improve their health status or even extend their lives, then our understanding of "equality for all," at least the notion that "all men are equal before death," may need to be re-examined.

4. Ethical Regulation of Risks in Medical Digital Twin Technology

Medical digital twin technology, as a cutting-edge technology, inevitably raises a series of ethical issues in its application in clinical experiments. For instance, improper technical operations may impose unnecessary burdens and stress on patients. Therefore, it is necessary to rely on modern ethical principles to guide the application of technology at a macro level. Moreover, medical ethics norms reflect the moral concepts and codes of conduct of medical staff, and China's medical ethics tradition particularly emphasizes the concepts of "people-oriented" and "the physician's benevolence."

However, addressing the ethical issues triggered by medical digital twin technology cannot rely solely on the efforts of patients and medical staff. It also requires supervision by ethical committees at the societal level and regulation by legislative bodies at the national level to ensure the responsible use of technology and the protection of patients' rights and interests.

Upholding the Principle of Respect for the Autonomy and Informed Consent Rights of Patients. Regardless of how advanced medical digital twin technology may be, it is essential to adhere to the ethical principle of respect throughout all stages of the technology, especially the foundational ones. The principle of respect originates from the four principles of biomedical ethics mentioned by American ethicists Beauchamp and Childress in their 1979 work, "Principles of Biomedical Ethics." Respect for autonomy, non-maleficence, beneficence, and justice together form the four principles of the application of bioethics. These four principles are often used as moral guidelines for resolving medical ethical issues*(13)*. The principle of respect primarily expresses recognition of an individual's autonomy and freedom rights, that is, it acknowledges the right of autonomous individuals to hold their views, thoughts, and to act based on their values and beliefs. This principle is crucial in ensuring that patients are treated as autonomous agents capable of making their own decisions regarding their healthcare, and that they are fully informed about the procedures, risks, and benefits associated with the use of medical digital twin technology.

The principle of respect primarily conveys the recognition of an individual's autonomy and freedom rights, which means acknowledging the right of autonomous individuals to hold their views, thoughts, and to act based on their values and beliefs*(14)*. The goal is to respect human rights and uphold dignity.

The significance of respect lies in preventing the disregard and even insult of patients' legitimate rights. When patients are faced with choices, it is essential to uphold both their positive and negative freedoms. In the process of adhering to this principle, healthcare providers should not obstruct patients' autonomous decision-making and actions. Even when patients have the will but lack

the capacity, healthcare providers should assist in building the patients' autonomy to support their decision-making. The scope of consideration for this principle of medical ethics is broad.

In addition to respecting patients' autonomy, healthcare professionals must also respect their right to informed consent. Before making medical decisions, patients should be fully informed of all relevant information, including diagnosis, treatment options, potential risks, and expected outcomes. Medical staff must ensure that patients understand this information to obtain valid informed consent. Moreover, respecting patients' privacy and confidentiality is part of the principle of respect. Healthcare providers need to protect patients' personal health information and must not disclose it to others or institutions without the patient's consent. It is also important to respect patients' cultural and personal differences, including their religious beliefs, lifestyles, and values. Medical staff should avoid imposing their personal views on patients and strive to understand and respect their cultural and personal backgrounds.

In the context of medical digital twin technology, especially during the clinical trial phase, assessments and supervision should be conducted on the implementation of patients' autonomy and informed consent rights, ensuring that patients receive information and make decisions freely with full respect and autonomy. On the other hand, there should be active public education about this technology to guide patients to have a deep understanding of the principles and procedures of medical digital twin technology, as well as their personalized treatment and maintenance plans. This empowers patients to exercise their rights in a real-time, dynamic, and effective manner, preventing them from making inappropriate decisions due to blind faith and worship of technology, thus truly achieving autonomy in their health and well-being.

To ensure the legitimacy and effectiveness of medical digital twin technology, implementing a mechanism for algorithmic transparency is of paramount importance. As the boundaries of technological algorithms continue to expand, the issue of "black box" algorithms has garnered widespread attention. The core of the black box problem lies in the lack of transparency, and thus, the key to addressing ethical issues is to break this opacity and promote algorithmic transparency. In the field of medical digital twin technology, not only is algorithmic transparency feasible, but patients are also increasingly able to hold the application of the technology accountable and supervise it through various means.

In the medical industry driven by artificial intelligence, algorithmic transparency can provide a new perspective on the authenticity and objectivity of medical practices, while also enhancing the advantages and authority of medical institutions and healthcare professionals in the application of technology. It is important to note that both the patient entity and its digital twin, as well as the execution process of the algorithm, are in a state of constant flux. The dynamic interaction between the physical entity and the digital model is a significant characteristic of this technology, and this trend of change adds to the complexity of the algorithmic black box.

To achieve transparent algorithmic operations, strengthening the connection between the patient entity and its digital twin is an effective and viable strategy. In the future, when medical digital twin technology is widely applied, doctors may not need to face patients directly for diagnosis and treatment. Therefore, ensuring the feasibility of treatment recommendations requires healthcare professionals to base their assessments on the changes in the patient's physical condition. When a patient's health status improves due to digital twin technology, it indicates that the algorithm is trustworthy, and this trust is built on effective communication and collaboration between the patient entity and the digital model.

For example, in the process of transferring data from the patient entity to the digital model, privacy and sensitive information may be involved. This necessitates enhanced communication and collaboration between the two to ensure that data that aids in making correct algorithmic decisions is extracted while fully protecting the patient's rights and interests, and simultaneously improving the patient's understanding of data algorithms.

The real world and things within it are always

changing, and if algorithmic decisions fail to take this into account, it becomes difficult to ensure the legitimacy and effectiveness of the technology, thus failing to meet the needs of patients and healthcare professionals. When the algorithmic decisions of medical digital twin technology yield positive results, they provide positive feedback to patients and healthcare professionals, which can then be applied to subsequent algorithmic decisions. This dynamic adjustment of the technology helps to enhance trust in it, reducing the uncertainty that patients may feel due to the complexity and lack of transparency of the algorithm.

Achieving fair allocation of medical resources through ethical and legal supervision. Ethics and law are both crucial measures in maintaining medical order, regulating and constraining the behavior of medical staff and patients. Firstly, ethical supervision suggestions and legal provisions should be proposed for multiple subjects of medical high-tech, such as patients, medical staff, medical institutions, and technology operation centers, especially for the directly relevant subjects of medical digital twin technology. Establish an ethics committee specifically for this technology to strengthen the ethical supervision and legal constraints on the operation of technology and data computation, clarify the responsibilities of each link and all participants, strictly carry out ethical supervision and review, avoid foreseeable risks, and safeguard the legitimate rights and interests of patients*(15)*.

Of course, the purpose of ethical supervision and legal constraints is to protect the legitimate interests and legal rights of all stakeholders. Ethics and law never favor any improper side. For instance, when applying medical digital twin technology, it can be combined with blockchain technology, which not only enhances the confidentiality of patient data but also provides a deeper level of protection for patients' human rights. Secondly, it is necessary to define the scope and extent of technology use. Establish guidelines for the operation of technology, and try to avoid invasive data collection and diagnostic treatment for patients during the implementation of this technology. At the same time, it is also important to consider potential emotional risks and minimize psychological harm to patients. Lastly, clarify the accountability mechanism through the formulation of laws and regulations. Strictly define and implement responsibilities among different subjects at various stages, such as information modeling, digital computation, and feedback of model results.

Malicious acquisition of information, algorithmic black boxes, violation of professional ethics, and contravention of social morals are strictly prohibited and severely sanctioned. In legislation, reference can be made to laws and regulations such as the Declaration of Helsinki to further refine and introduce legal provisions and institutional norms related to medical digital twin technology. The existence of ethics and law not only serves to restrain patients and medical staff but also provides a basis for the systems and actions of hospitals and governments. The participants in medical digital twin technology include not only patients and medical staff but also hospitals and governments. The economic nature of hospitals determines their economic goal of maximizing economic benefits, but the particularity of medical services also implies that hospitals must undertake the public welfare responsibility of ensuring the safety of patients' lives.

Therefore, the basis for hospital operations and philosophy is to have both economic benefits demands and the fulfillment of public welfare responsibilities, which also requires the government to ensure that hospitals fulfill their social responsibilities while obtaining economic benefits by formulating a series of policies and regulations. First, it is necessary to accelerate the construction of a national big data medical center to achieve the coordination of patient medical data. Taking medical digital twin technology as an example, it is possible to achieve the organic integration of patients' historical health data and future health data. Second, the government should coordinate the allocation of medical resources between developed and underdeveloped areas from the perspective of the macro medical market, so that all citizens, including vulnerable groups, can enjoy the right to equal treatment.

Of course, the government's construction of a unified medical security system for all is oriented towards the fairness of outcomes, with the aim of ensuring that low-income groups can also enjoy

the "most universal" medical services. The promotion of the popularization and fair use of medical digital twin technology still requires the joint efforts of the government, society, hospitals, medical staff, and patients.

5. Conclusion

While medical digital twin technology holds broad prospects for future development and profound social and moral benefits, it also faces numerous pressing challenges that need to be addressed. These challenges are not only reflected in how to ensure the security of the collection and processing of a large amount of personal health data by medical digital twin technology, but also involve biases and reliability issues arising from big data algorithms during the operation of the technology. Lastly, the digital divide and issues of fairness generated within medical digital twin technology also provoke deep thought. In response to these ethical risks and challenges, it is essential to strictly adhere to medical ethical principles and relevant ethical norms to avoid them.

Only by ensuring that the legitimate and reasonable rights and interests of all stakeholders in medical digital twin technology—including patients, medical institutions, developers, and policymakers— are fully protected, can its unique value in enhancing individual health management levels and promoting the overall optimization of medical services be truly realized. At the same time, the successful promotion and application of this technology also depend on a broad consensus and cooperation across society, ensuring that technological development and ethical responsibility go hand in hand, achieving a high degree of unity between individual values in the medical field and overall social benefits.

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