The Current Development Status and Challenges of Digital Twin Technology in the Domain of Precision Nursing

Xingyi Mu[1], Jingyu Xu[2*]

[1] Nursing Department, Affiliated Hospital of Zunyi Medical University, Zunyi, Guizhou, China

[2] Zunyi Medical University, Zunyi, Guizhou, China

[*] Corresponding author

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Abstract: With the rapid development of emerging artificial intelligence technology, digital twin technology provides more possibilities for the development prospects of precision care. Digital twin technology can comprehensively use the comprehensive data information of objects to build virtual entities, and improve the accuracy of model classification and prediction by building dynamic connections between entities and virtual entities. At present, the application of digital twin technology in the field of precision care not only includes the treatment of difficult specialized diseases, but also includes the whole life cycle and the whole population level of health management. This paper summarizes the research progress and challenges in the application of digital twins in the field of precision nursing, providing ideas and directions for further breaking through the technical bottleneck, broadening the application field, accelerating the application and strengthening laws and regulations.

***Keywords*:** digital twins; artificial intelligence; precision care; review

1. Introduction

By leveraging multidisciplinary collaboration and applying cutting-edge technology, we aim to thoroughly analyze the phenotypic characteristics as well as key elements of biometrics, lifestyle, and environmental exposure from population-level biological groups down to individuals. Our ultimate goal is to provide personalized, timely, accurate, and high-quality nursing services throughout the entire lifespan of our patients while ensuring their health is safeguarded in a safe, efficient, and cost-effective manner.

With the rapid advancement of transcriptomics, proteomics, epigenomics, and metabolomics, omics data are continuously generated in abundance, providing a robust foundation for precise nursing practices and serving as an essential prerequisite for further advancements[1].The national resources and policies towards "precision nursing" have experienced a significant shift in recent years, thanks to the support of national policies and resources. As a result, nursing science has witnessed unparalleled development and now plays an indispensable role in accurate forecasting analysis and other domains[2].The optimal integration of health management based on artificial intelligence and bioinformatics data is a crucial obstacle to the sustainable development of precision care, necessitating the urgent resolution of these outstanding challenges[3, 4].

2. Development history and characteristics of digital twins

The concept of "twin" was initially introduced in the Apollo space program as early as 1970, and it was NASA's John Vickers who first coined the term "digital twin" in 2002[5].Currently, the industry widely acknowledges that the concept of "DT" was introduced by Professor Michael Grieves in 2002 in the United States and defined as an "information mirroring model." It can be comprehended as a virtual information structure that encompasses a range of virtual information from the microscopic atomic level to the macroscopic geometric level. In ideal circumstances, any information obtainable from a physical entity can be acquired within a digital twin virtual environment[6].The digital twin was proposed by NASA in 2012 as a conceptual model for predicting aircraft structural life and ensuring structural integrity[7],The digital twin technology has gradually emerged as a prominent focus in the aerospace industry since then.The Digital Twin (DT) is essentially a virtual model constructed using digital technology, which enables real-time simulation, analysis, and optimization of the behavior of physical entities. This is achieved through continuous data fusion and information interaction between the virtual space and the physical world[8,9]

3. The utilization of digital twin technology in the precise management of specialized diseases.

3.1 Enhanced precision care of chronic diseases through the application of digital twin technology

Padmapritha Thamotharan et al[10] introduction of a human digital twin (HDT) framework has revolutionized the precision care of elderly patients with type 2 diabetes by leveraging diverse patient-specific data and constructing predictive and management models. The key advantage of HDT lies in its capability to handle historical as well as real-time data, which is absent in current approaches. With HDT, personalized background data can be tailored for precise care of E-T2D patients. Isabel Voigt et al[11] have developed a comprehensive model for predicting the subtypes of multiple sclerosis (MS) disease, which integrates clinical, biological, molecular, and imaging markers to understand their impact on individual patients' lives. The simulation of similar health conditions, risk factors, and disease development characteristics in real-world MS patients contributes to personalized and effective care by integrating data from various sources in a standardized manner. This approach facilitates precision clinical pathways, supports doctor-patient communication, and enables shared decision-making.

3.2 Enhanced application of digital twin technology in precision care for cancer

The digital twin technology was employed by Zhang et al[12] to facilitate precision nursing in lung cancer, enabling the collection of image data with the unique advantages offered by this technology. They utilized a Disney model to depict the lung organs of patients and directly mapped patient data to model parameters, allowing for direct comparison of patient trajectories and experiences. This approach enables verification of progress and results for different intervention strategies through computational models. By utilizing digital twin technology, healthcare professionals can analyze the potential impact of various treatment interventions on lung cancer, thereby facilitating more informed decision-making and precise care for patients[13].

3.3 Application of digital twin technology in precise nursing of nervous system diseases

Mark Connelly et al[14] utilized a combination of digital technology (DT) and extended reality (XR) technology to develop a system aimed at investigating the impact of relaxation training on preventing migraines in children. Within an extended application system, users are able to perceive and interact with either a fully immersive virtual environment or virtual objects that are superimposed onto their current view of the physical environment, known as augmented reality (AR) and mixed reality (MR). In this particular context, virtual reality (VR) has demonstrated analgesic and anti-anxiety efficacy by effectively capturing attention through pleasurable sensory stimuli while regulating autonomic, affective, and evaluative pain signaling pathways. By augmenting XR-based relaxation training with neurofeedback reinforcement, it is possible to assist children in preventing migraine attacks by developing skills that regulate neural mechanisms believed to be involved in triggering such attacks.

4. Enhanced utilization of digital twin technology in precision health management

Lehrach et al[15] developed a disease prevention system called "virtualtwins" that integrates image data and clinical data to systematically model and analyze the disease status and biological characteristics of individual patients in Europe. Medical professionals can accurately assess the treatment effects of different interventions through the virtual simulation system, enabling them to select the most suitable intervention measures and formulate personalized treatment plans based on each patient's condition and specific needs. This not only enhances nursing outcomes but also reduces healthcare costs. In the field of precision health management in cardiology, Jorge Corral-Acero et al[16] have recently developed a model that enables clinicians to deliver personalized precision diagnosis and care to patients by considering individual variances and integrating a wide range of biological, environmental, and lifestyle data that impact cardiovascular outcomes. However, further efforts are needed to promote the widespread adoption of these models in clinical practice.

5. Enhanced potential and obstacles of digital twin technology in precision healthcare

In the field of precision nursing, the application prospect of digital twin technology is immeasurable and cannot be ignored. A digital twin can capture an individual's health data, including genetic information, medical history, and lifestyle factors. This comprehensive dataset can be utilized to create personalized treatment plans tailored to each person's unique needs. By analyzing extensive health data from multiple dimensions, personalized screening plans for early diagnosis can be developed. The possibility of remote monitoring enables medical professionals to remotely track patient vital signs, symptoms, and treatment adherence while providing timely interventions for patients in remote areas.

Data and analystics serve as the foundation for the success of digital twins. However, both electronic health records and information system records remain isolated and fragmented rather than being amalgamated with data from diverse sources. The data of digital twin technology possesses the characteristics of high density and low value, necessitating real-time processing through advanced computer algorithms to enhance data transfer efficiency. Artificial intelligence (AI) algorithms, as a pivotal technology in digital twins, require a high-performance infrastructure comprising cutting-edge hardware and software for their execution. However, the current challenge lies in the exorbitant cost associated with installing and operating these systems [17]. Therefore, to establish a comprehensive digital twin technology framework, it is imperative to optimize and enhance the internet technology infrastructure first. The application of medical cyber-physical systems (MCPS) and cloud computing can overcome technical bottlenecks in predictive management and accurate diagnosis and treatment while further enhancing their effectiveness [18].

6. Enhanced the utilization of digital twin technology in the domain of precision nursing

Due to various subjective and objective factors, the application of digital twin technology in the field of medical care is limited, and it also has shortcomings in predicting and managing disease risks. Group precision care is an inevitable trend. When medical information can flow seamlessly across different regions and be shared in real time, it is expected to create an efficient digital urban healthcare system. Essentially, digital urban healthcare is a result of combining digital twin technology with communication information technology. Through this integrated approach, it opens up channels for group health management and individualized medical care, optimizing and adjusting diagnosis and treatment methods while effectively mitigating disease risks, enhancing the efficiency of health management, and reducing medical costs [19]. Moreover, as virtual replicas of physical systems, digital twins can simulate pathogen spread and predict outbreaks accurately to evaluate various interventions. With the aid of artificial intelligence (AI), digital twin technology can assimilate multiple data sources to improve prediction accuracy further while optimizing resource allocation and facilitating public health decision-making [20].

7. The laws and regulations should be enhanced

In order to prevent digital twin technology from being exploited by criminals for the purpose of stealing patient privacy, it is imperative for the state to enhance regulatory policies. Additionally, the industry should establish management norms that clearly distinguish between private and confidential information, accurately address data sharing requirements, and ensure the systematic and standardized development of digital twin technology in precision care [21]. Therefore, relevant authorities must strengthen legal supervision and define the application scope of digital twin technology in precision medicine. From a perspective of social morality and ethics, digital twins have the potential to perpetuate or exacerbate social prejudice and racial discrimination within the medical system [22]. It is undeniable that the social mechanism, hardware conditions and laws and regulations that support the development of digital twin technology in the field of precision nursing are still in an imperfect stage, and it is necessary for government agencies to formulate relevant policies and improve the boundary planning of laws and regulations, such as supporting data management and strengthening the construction and training of precision nursing personnel to promote the faster development of precision nursing. To better meet people's health needs.

References

[1] FERRANTI E P, GROSSMANN R, STARKWEATHER A, et al. Biological determinants of health: Genes, microbes, and metabolism exemplars of nursing science [J]. Nursing Outlook, 2017, 65(5): 506-14.

[2] HICKEY K T, BAKKEN S, BYRNE M W, et al. Precision health: Advancing symptom and self-management science [J]. Nursing Outlook, 2019, 67(4): 462-75.

[3] ARCHIBALD M M, BARNARD A. Futurism in nursing: Technology, robotics and the fundamentals of care [J]. Journal of Clinical Nursing, 2017, 27(11-12): 2473-80.

[4] NG Z Q P, LING L Y J, CHEW H S J, et al. The role of artificial intelligence in enhancing clinical nursing care: A scoping review [J]. J Nurs Manag, 2022, 30(8): 3654-74.

[5] GRIEVES M, VICKERS J. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems [M]. Transdisciplinary Perspectives on Complex Systems. 2017: 85-113.

[6] STARK R, FRESEMANN C, LINDOW K. Development and operation of Digital Twins for technical systems and services [J]. CIRP Annals, 2019, 68(1): 129-32.

[7] GLAESSGEN E, STARGEL D. The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles [Z]. 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference
20th AIAA/ASME/AHS Adaptive Structures Conference
14th AIAA. 2012.10.2514/6.2012-1818
[8] GUO J, LV Z. Application of Digital Twins in multiple fields [J]. Multimedia tools and applications, 2022, 81(19): 26941-67.
[9] GUO J, LV Z. Application of Digital Twins in multiple fields [J]. Multimedia tools and applications, 2022, 81(19): 26941-67.
[10] THAMOTHARAN P, SRINIVASAN S, KESAVADEV J, et al. Human Digital Twin for Personalized Elderly Type 2 Diabetes Management [J]. Journal of Clinical Medicine, 2023, 12(6).
[11] VOIGT I, INOJOSA H, DILLENSEGER A, et al. Digital Twins for Multiple Sclerosis [J]. Frontiers in Immunology, 2021, 12.
[12] ZHANG J, LI L, LIN G, et al. Cyber resilience in healthcare digital twin on lung cancer [J]. IEEE access, 2020, 8: 201900-13.
[13] HERNANDEZ-BOUSSARD T, MACKLIN P, GREENSPAN E J, et al. Digital twins for predictive oncology will be a paradigm shift for precision cancer care [J]. Nature Medicine, 2021, 27(12): 2065-6.
[14] CONNELLY M, BOORIGIE M, MCCABE K. Acceptability and tolerability of extended reality relaxation training with and without wearable neurofeedback in pediatric migraine [J]. Children, 2023, 10(2): 329.
[15] LEHRACH H, IONESCU A, BENHABILES N. The Future of Health Care: Deep Data, Smart Sensors, Virtual Patients and the Internet-of-Humans (White Paper-2016) [Z]. July. 2021
[16] POPA E O, VAN HILTEN M, OOSTERKAMP E, et al. The use of digital twins in healthcare: socio-ethical benefits and socio-ethical risks [J]. Life Sciences, Society and Policy, 2021, 17(1)
[17] FULLER A, FAN Z, DAY C, et al. Digital twin: Enabling technologies, challenges and open research [J]. IEEE access, 2020, 8: 108952-71.[21] GUO J, LV Z. Application of Digital Twins in multiple fields [J]. Multimedia tools and applications, 2022, 81(19): 26941-67.
[18] SHAIKH T A, RASOOL T, VERMA P. Machine intelligence and medical cyber-physical system architectures for smart healthcare: Taxonomy, challenges, opportunities, and possible solutions [J]. Artif Intell Med, 2023, 146: 102692.
[19] BARRICELLI B R, CASIRAGHI E, FOGLI D. A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications [J]. IEEE Access, 2019, 7: 167653-71.
[20] ABBO L M, VASILIU-FELTES I. Disrupting the infectious disease ecosystem in the digital precision health era innovations and converging emerging technologies [J]. Antimicrob Agents Chemother, 2023, 67(10): e0075123.
[21] CARNEVALE A, TANGARI E A, IANNONE A, et al. Will Big Data and personalized medicine do the gender dimension justice? [J]. ai & Society, 2023, 38(2): 829-41.
[22] FERDOUSI R, LAAMARTI F, HOSSAIN M A, et al. Digital twins for well-being: an overview [J]. Digital Twin, 2022, 1: 7.