DIGITAL TWIN TECHNOLOGY IN HEALTHCARE SYSTEM

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Acknowledgement: Authors are thankful to the Hon. Shri. Babanrao Pachpute Vichardhara Trust's Parikrama Diploma in Pharmaceutical Sciences, Kashti for extending requested facilities in commencement and completion of this work.

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ABSTRACT

Healthcare systems are undergoing a change thanks to digital twin technology, which uses virtual simulations, advanced analytics, and real-time data integration to improve patient care, enable predictive analytics, streamline clinical operations, and support training and simulation. Digital twins can provide individualized treatment regimens based on individual features, medical history, and real-time physiological data since they can collect and analyze vast amounts of patient data from several sources. Machine learning algorithms enable predictive analytic and preventative interventions, which facilitate the early identification of health hazards and preemptive measures. By examining resource allocation and workflows, digital twins can optimize clinical operations, resulting in more efficient procedures and better patient care. Furthermore, digital twins can give medical practitioners a secure and authentic setting in which to practice difficult procedures and improve their skills. Digital twin adoption in healthcare might lead to major improvements in patient outcomes, increased patient safety, and stimulate innovation in the sector. In particular, the digital twin can predict neurological complications, using it in precision medicine, modeling cancer care and treatment, predictive analysis and machine learning, and combining the opinions of different doctors. Digital twin technology can help to reduce healthcare costs by optimizing medical procedures and reducing the need for trial-and-error approaches. As this technology continues to evolve, it has the potential to revolutionize healthcare and improve patient outcomes.

Keywords: Healthcare, Digital health, Digital twin, Patient safety, Medical history, Workflow optimization.

DIGITAL TWIN TECHNOLOGY

The digital twin is emerging as a transformative force in healthcare systems, revolutionizing the delivery of patient care. Using real-time data integration, advanced analytics, and virtual simulations, digital twins provide better patient care, predictive analytics, optimization of clinical operations, and training and simulation capabilities (1). Digital twins provide improved patient care by allowing medical professionals to collect and evaluate a multitude of patient data from several sources, such as wearables, medical equipment, and electronic health records (EHRs) (2). Customized treatment regimens are created possible by this comprehensive understanding of the patient, which takes into account personal traits, medical history, and current physiological data. Healthcare practitioners can use digital twins to accurately diagnose patients, monitor them in real time, and provide patients the power to actively participate in their own care (3, 4). Digital twin technology uses machine learning algorithms and patient data analysis to provide predictive analytics and preventive treatments. Digital twins have the ability to identify high-risk individuals, forecast the course of a disease, and suggest preventive treatments. The allocation of resources within healthcare systems, long-term results, and patient safety are all enhanced by this proactive strategy (5). Because digital twin technology makes use of realistic simulations, powerful analytics, and real-time data integration, it may therefore be able to completely change healthcare systems. It can facilitate training and simulation, improve clinical operations, provide predictive analytics, and improve patient care. The potential for the use of digital twins in healthcare systems to enhance patient outcomes, operational effectiveness, and general healthcare quality was the main emphasis of this review.

ENHANCED PATIENT CARE THROUGH DIGITAL TWIN TECHNOLOGY

By utilizing real-time data integration, sophisticated analytics, and individualized insights, digital twin technology holds great promise for improving patient care (1) With the use of these tools, healthcare professionals will be able to collect and evaluate a vast amount of patient data from a variety of sources, including wearables, medical gadgets, electronic health records (EHRs), and genetic data (2,7) Digital twins empower patients to actively participate in their own care (8). By providing patients with access to their digital twin data, including personalized health insights, treatment plans, and progress tracking, patients can become more engaged in managing their health (9). This increased engagement leads to better adherence to treatment regimens, lifestyle modifications, and self-management practices. Moreover, digital twins can facilitate communication and collaboration between patients and healthcare providers, promoting shared decision-making and patient-centred care (10).

Digital twins are able to recognize high-risk patients, anticipate possible problems, and suggest preventive actions by examining patient data and past trends. In the end, this proactive approach to care improves patient safety and long-term results by enabling healthcare practitioners to intervene early, prevent adverse events, and optimize treatment regimens based on anticipated patient responses (11).

Digital twins can facilitate seamless continuity of treatment by securely exchanging patient data among various healthcare locations and providers (12). By ensuring that all participating healthcare professionals have access to the most recent and thorough

patient information, this helps to minimize test duplication, promote coordinated care, and lower the risk of medical errors. Digital twins have the potential to facilitate better communication and collaboration among healthcare teams, hence improving the overall quality of patient care (13,14).

VARIOUS FEATURES AND SERVICES OF DIGITAL TWIN FOR HEALTHCARE

Fig. 1 illustrates the different related services and issues using Digital Twin technology for healthcare. It details the intelligent services offered by this most recent cutting-edge and supportive approach—a digital twin for the healthcare industry. It primarily focuses on patient health services, data-related facts and concerns, lowering the costs of patient treatment and care, high-quality services, challenges relating to societal disruptions, etc. These services also demonstrate how patient care has improved during therapy to promote healing and a speedy recovery. [15], [16],

Four technologies are used by Digital Twin to generate visual representations, gather, store, and analyze data, and produce informative content. These technologies comprise IoT, cloud, AI, and extended reality. Understanding the behavior of physical equipment and having remote view of assets, systems, and processes are two major advantages of digital twins. In order to forecast future events, it employs a prediction algorithm that leverages insights from asset behavior. Furthermore, through automating and enabling better decision-making, these insights increase productivity and profitability [17], [18],

PREDICTIVE ANALYTICS AND MACHINE LEARNING

Three areas make up the broad field of paediatric cancers: diagnosis, a range of therapy choices, and extensive patient follow-up. This industry is the perfect case study for the confluence of machine learning and digital twin technologies because of the numerous data points that are generated in this way throughout time and geography. Predictive analytics is the field that lies at the interface of computer science and statistics. In order to uncover valuable patterns from the complex relationships seen in big data, machine learning methods are often applied to the study of the data (19). This method has the potential to derive clinically relevant prognostic patterns of disease for use in healthcare research.

PREDICTIVE ANALYTICS AND PREVENTIVE INTERVENTIONS THROUGH DIGITAL TWIN TECHNOLOGY

Using patient data and past trends, digital twins can model the course of a disease (20). Digital twins have the ability to create prediction models to anticipate the course of a disease by examining trends, treatment outcomes, and patient features. With the use of this data, medical professionals may better plan treatments, foresee future issues, and implement interventions that will either stop or reduce the advancement of the disease. By taking into account the unique characteristics of each patient, including genetics, lifestyle, and response histories, digital twins enable individualized disease modeling that produces more precise forecasts and specialized interventions (21).

By instantly informing medical professionals of possible health hazards, digital twins can facilitate proactive treatments and preventive care (22). Digital twins can discover early warning indicators, detect changes from normal health parameters, and initiate

timely interventions by continuously monitoring patient data. By taking a proactive stance, medical professionals can treat patients before they get worse, which lowers healthcare costs, avoids hospital stays, and enhances patient outcomes. Personalized health suggestions, screening reminders, assistance with medication adherence, and lifestyle changes are all part of preventive care provided by digital twins (23).

DIGITAL TWIN APPLICATIONS FOR HEALTHCARE

In order to help and offer a safe environment for evaluating the effects of changes on hospital performance without jeopardizing the actual location, digital twins virtualize hospitals in a medical setting. A hospital's digital twin would give access to data-driven insights on staffing, capacity, operational strategies, and care models, enabling decision-making and readiness for future problems. A digital twin might keep an eye on capacity all the time. Staff schedules might be optimized as a result, and valuable resources like beds and operating rooms may be assigned and quickly deployed when needed. Digital twin applications for healthcare as shown in Table 1.

CONCLUSION

In summary, there is great potential for digital twin technology to transform healthcare systems and improve patient care. Digital twins provide individualized treatment plans, predictive analytics, enhanced clinical operations, and immersive training possibilities by combining real-time data, advanced analytics, and virtual simulations. Healthcare workers are better equipped to diagnose patients accurately, monitor them in real time, and take preventive measures to stop unfavorable outcomes when they use digital twins. Additionally, it fosters cooperative decision-making between patients and healthcare professionals and gives individuals the ability to actively engage in their own care. Digital twins also help healthcare organizations operate more efficiently by streamlining procedures, allocating resources optimally, and improving operational efficiency. Digital twin technology has enormous potential in the healthcare industry, and its application could lead to notable improvements in patient outcomes, safety, and innovation. but in order for it to be implemented successfully, issues with data privacy, interoperability, data quality, ethics, resource intensity, workflow integration, validation, education, scalability, and cultural shifts must be resolved. Digital twin technology has the potential to completely transform healthcare systems once these obstacles are overcome, resulting in better patient outcomes, more effective operations, and higher-quality care.

ACKNOWLEDGEMENT

Authors are thankful to the Hon.Shri.BabanraoPachputeVichardhara Trust’s Parikrama Diploma in Pharmaceutical Sciences, Kashti for extending requested facilities in commencement and completion of this work.

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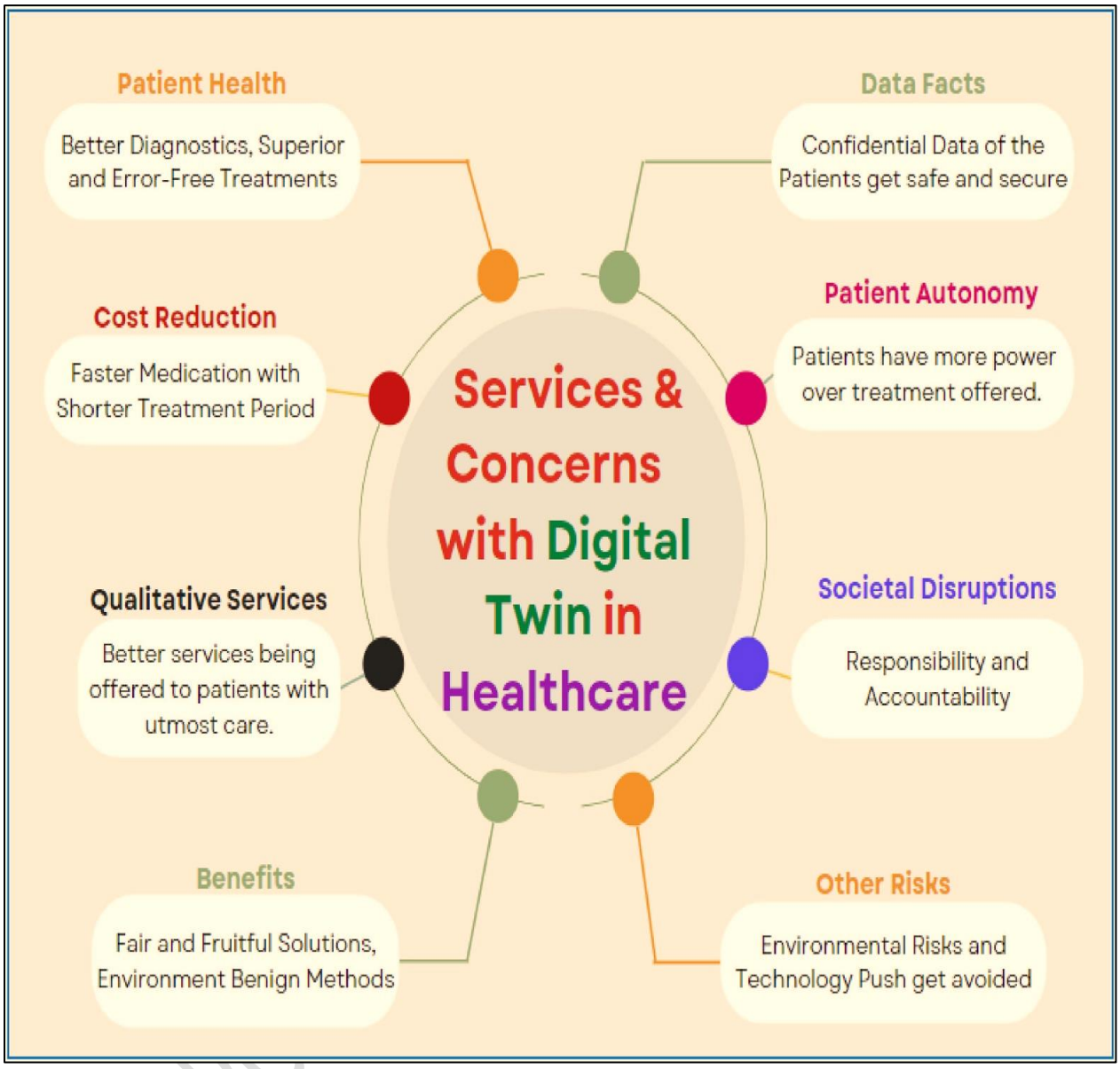

Fig. 1. Services & concerns with digital twin in healthcare.

Table 1. Digital twin applications for healthcare.

Sr. No.	Applications	Descriptions
1.	Patient care	The implementation of Digital Twins can enhance researchers' understanding of customized medicine, patient care, and the management of persistent illnesses. Digital twins of the human body as a whole and of particular organs such as the kidneys, lungs, and heart are being developed at an advanced stage. This can be used to simulate any specific person's organ, allowing for thorough testing before applying the results to the patient. Digital twins and utilization models could increase the resources' accessibility. Identifying and manipulating items improves patient outcomes, expedites admissions, and increases room turns. Predictive maintenance, which enhances the functionality and accessibility of less expensive assets including less expensive imaging equipment, lab automation, and surgical robots, is also made possible by digital twins. Medical equipment, practices, and personnel are only a small part of effective resource management.
2.	Better personal health results	Growing computing and algorithmic capacity in the healthcare sector makes it possible for technology to create a digital twin tailored to each patient, promoting human diversity and improving personal health outcomes. More coordinated and continuous basic research and development will be required in order to fully realize the promise of the digital twin. It makes complex assets and processes easier for businesses to understand and manage. Automatic data transfer between the real, physical object and its digital representation is possible with a digital twin. Using a digital twin that contains the patient's genetic information, imaging data, and test results, the physician can determine the best course of action, which may involve surgery, radiation therapy, or hormone therapy. Digital Twin helps with the early diagnosis of chronic sickness to manage chronic disease in a large

		population by analyzing physiological and behavioural data.
3.	Diagnostics and medical training	A patient model created prior to the actual surgery is called a digital twin. To avoid damaging human anatomy, a multidisciplinary team performs virtual surgery for medical diagnostics and training. With this real-time model, residents can practice surgery on patients and gain more knowledge about the physiological and anatomical differences between individuals. The same technology being used to understand long-term symptoms can also be used to help create medical digital twins, which in turn can help provide high-resolution, disease-specific digital twins that physicians and researchers can use for a range of other applications in the healthcare industry. AI-driven research and digital twins will help hospitals and research facilities worldwide, enabling the widespread use of technology to improve health, education, and economic prospects. Many more industries and businesses will employ digital twins to digitize their processes, and these industries and businesses will require a dispersed, hybrid, multi-cloud environment. They will require a technology partner who can secure their data, simulation, and the real-world product, process, or person it represents while also offering the appropriate hardware, software, and integration services for data management.
4.	Enhance medical innovation	Digital twins could help with medical innovation and regulatory approval in the healthcare industry. This method may one day help doctors maximise the effectiveness of personalised treatment plans for each patient. Medical professionals may benefit from using digital twins to expedite, lower the cost, and improve patient safety when releasing life-saving innovations onto the market. Individual and demographic data are integrated into computer-based or in silico models to create digital twins. These digital representations of human physiology aid in scientific research into diseases, new therapies, and medical devices. By employing digital twins to predict and prevent patient crises like cardiopulmonary or respiratory arrest, sometimes known as code blues, more lives could be saved.

5.	Research and development	Digital twin simulations are utilized in the healthcare sector to create models that supply data for R&D. It is used by physicians to evaluate and reevaluate personnel, capacity, care delivery strategies, and other aspects. A digital twin in the medical field could monitor and analyze patient data by using a biophysical model. By analyzing a patient's previous and current data, a doctor can manage the patient's healthcare remotely, offering the most advanced care possible. Digital twins modify medical practices and improve patient happiness through machine learning techniques. The Internet of Things is the primary technology used by all Digital Twin apps. The Internet of Things is based on the collection of data from physical objects using sensors. Then, using this data, the actual object is digitally replicated so that it may be studied. Cloud computing makes it possible to store all data in a virtual cloud and make it easily accessible from anywhere, which is useful for digital twin applications that handle massive volumes of data. Artificial intelligence is a potent analytical tool that can automatically analyze data and offer pertinent insights. It can also forecast probable results and suggest averting such issues.