Hospitals 2040

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Abstract

The healthcare industry is experiencing a rapid transformation driven by technological advancements and the increasing need for more efficient and smarter healthcare services. The chapter aims to 1) explore the evolving healthcare landscape 2) understand impact of disrupting trends and technologies in healthcare delivery and hospital advancements 3) highlight outlook of hospitals 2040. The rapidly advancing innovations are expected to completely revolutionize patient care, diagnosis, treatment, and the healthcare industry. However, ethical considerations, data privacy, reliability and regulatory compliance remain critical aspects of this evolving landscape.

This paper thoroughly discusses these requirements and emphasises how crucial they are to determining the future course. It also takes a thorough look at modern technologies like quantum computing, Industry 4.0, and the idea of digital twins, analysing how these might be incorporated with improvements in hospitals. Development of metaverse for intelligent healthcare will enlarge the hospital into homes. The vision for the future of hospitals entails a transformation characterized by intelligent collaboration, innovation and seamless integration of patient care and delivery. The roadmap to Hospital 2040 is aimed at making healthcare better and more accessible for everyone.

Keywords: Innovations, healthcare industry, technologies, Hospital 2040

Introduction

Healthcare is changing and developing, creating new opportunities for patients and the industry. A proactive care strategy is quickly becoming the norm in modern healthcare. Post COVID-19, healthcare information technology (IT) has experienced a massive transformation. Healthcare discrepancies were widespread in the past, but the pandemic has brought them to light. For instance, conventional healthcare used to be reactive. Many believed it to be patient-centred, yet it was either plan- or premium-centric. The healthcare system briefly fell apart when people who needed emergency care rushed to hospitals. As a result, resources ran out and supply chain issues emerged. The importance of the cloud, analytics platforms, and data management has all increased. New sectors have emerged because of the transformation fuelled by these technologies, such as the $1.5 trillion wellness sector, according to McKinsey. Innovative platforms, technology, and care management strategies are becoming more and more crucial [1]. The path to hospital 2040 is already underway, and it holds enormous promise for improving lives everywhere.

Hospital 2040 is set to steer in a new era of healthcare, powered by a data-driven paradigm and the incorporation of cutting-edge technologies. This forward-thinking healthcare landscape is intended to not only maintain the greatest medical standards, but also to handle the specific issues given by an aging and longer living population. By doing so, it hopes to slow the rise in healthcare expenses while easing the pressure on our hardworking medical staff [2].

Hospitals will emerge into multifunctional hubs in this future healthcare ecosystem, with every aspect of their operations effortlessly digitized, making data their cornerstone resource. This digitization will not only streamline administrative and clinical operations but will also provide crucial insights to healthcare providers for informed decision-making. Digital twins, quantum computing, virtual worlds, and gene editing technologies will be used in hospitals of the future to optimize resource allocation, adapt treatment programs, produce scientific breakthroughs, and improve patient outcomes.

Furthermore, hospitals in 2040 will provide a variety of services beyond standard medical care. They will act as hubs of innovation, research, and teaching, encouraging collaboration among healthcare stakeholders. This all-encompassing strategy ensures that healthcare institutions become self-sustaining entities, adjusting to society's changing requirements while remaining at the forefront of medical expertise. The development of treatments that contribute to prolonging our healthy life expectancies and curing

diseases that are difficult to treat are tedious in today's world compared to in 2040 when we will be transferring our minds to robots or cyberspace or the meta verse enabling worldwide connectivity, productivity of the healthcare industry as well as greater impact and further reductions to social security costs.

Material and methods

Cutting-edge technologies such as Artificial Intelligence (AI), machine learning (ML), digital twins, quantum computing, nanotechnology, genomics, and others have demonstrated significant potential in shaping the future of hospitals in 2040. These technologies are instrumental in achieving goals related to accessible healthcare, patient-centred care, cost-effectiveness, education and training, sustainability, infrastructure, design, digital transformation, and personalized medicine, among others [Figure 1].

In this paper, as detailed below, we have outlined the major technologies impacting hospital of the future. The selection of these technologies was based on authors' consideration and literature reviews.

Figure 1: Illustration depicting technologies transforming hospital of the future

Individual health digital twin approach

Integrating a diverse array of data sources including Human Medical Records (HMR), images, genomic data, biomarkers, real-world data, wearables data, behavioural data and cyber space interests can yield a comprehensive dataset for constructing a personalized health digital twin. However, the adequacy of this dataset depends on the specific objectives and applications of the digital twin, as well as the quality of the data used. Predictive intelligence based on subtle observations leads us to healthier and longer lives. Several crucial considerations must be addressed such as harmonizing the data from various sources for a unified health view integrated with real-time or near-real-time monitoring to adapt to changing health conditions (continuous monitoring), with health information exchange standards (interoperability) to develop customized digital twin based on individual genetics, medical history, and lifestyle (personalization). Advanced ML and AI models are essential for understanding such diverse data sources, including structured and unstructured data (discussed further in the paper), as well data quality and integration mechanisms to ensure accurate, up-to-date, and well-integrated data to prevent misleading insights. With the advancement of AI, the quality of data communities and the flow chart of decision support will be updated, which will generate new discoveries. Moreover, strict privacy and security

measures are necessary to protect sensitive health data, complying with regulations like Health Insurance Portability and Accountability Act (HIPAA) or General Data Protection Regulation (GDPR), while addressing ethical concerns when using sensitive data, emphasizing consent and transparency (ethical considerations) and ensuring the digital twin's accuracy and reliability of the through validation of clinical and medical device studies. [3].

Differential AI diagnostics

This explores methods addressing how to speed up and compensate shortage of high-quality decision making in the context of multilingual and AI-driven differential diagnostics. Combining diverse technologies and approaches allows us to achieve accurate and reliable differential diagnostics and patient treatment through speech-to-text and image-to-voice interpretation synthesizing international languages [4].

A comprehensive breakdown of the key steps for accomplishing this are as follows:

- Speech-to-Text (Automatic Speech Recognition – ASR) can be used to transcribe spoken language with improved accuracy [5].
- The reproduction of text/image/sensor information into speech is therefore of primary importance in health care to support a very large number of home hospital patients with visual impairment.
- Natural Language Processing (NLP) can be employed to perform language detection, translation, identification of patient's language and sentiment analysis. Also, machine translation can be utilized to convert transcribed text into different languages. Extracting relevant details from the transcribed and translated text is crucial for differential diagnosis.
- Computer vision can be used to interpret medical images whereas, voice synthesis (Text-to-Speech – TTS) and voice interpretation tools can be employed to transform, translate, and synthesize medical information, diagnosis, and treatment plans into natural sounding speech across languages and patient's preferred languages.

- An integrated communication platform is necessary for seamless data input and output from speech and text. To improve the accuracy and compliance, continuous training, and updates with data privacy regulations (e.g., HIPAA, GDPR) are to be ensured.
- Additionally, continuous input from healthcare professionals and patients are required to enhance the overall system performance.

This holistic strategy combines cutting edge technologies like ASR, NLP, machine translation, computer vision, and TTS, along with proper planning and a focus on privacy and security considerations, enabling seamless communication between healthcare providers and multilingual patients and aiding in the diagnostic and treatment procedures.

Industrial revolutions

Industry 5.0 and 6.0 represent advanced stages of industrial development and transformation, building upon the concepts and technologies of Industry 4.0. In Industry 5.0, there's a focus on close collaboration between humans and machines, customization of products, sustainability, and increased flexibility in manufacturing processes [6]. Industry 6.0 builds upon the digitalization of Industry 4.0 with seamless cyber-physical integration, AI dominance, hyperconnectivity across supply chains, quantum computing, advanced materials, and heightened attention to ethical and regulatory challenges. These stages reflect the ongoing evolution of the industrial landscape, but their adoption varies across industries and regions.

Quantum computing in large

Quantum computing is a rapidly emerging multidisciplinary field which has a potential to have application in various sectors including healthcare, automotive, finance, material science and beyond. Although the complete range of its impact is still under investigation, here are some domains where quantum computing is anticipated to bring about noteworthy transformations [7]. Quantum computing accelerates data analysis and simulations in chemistry, physics, and astronomy and offers faster data analysis and pattern recognition, enhancing AI, especially in natural

language processing and optimization [8], thereby accelerating diagnostics, medical imaging, genomic analysis, drug discovery, and material development [7]. Additionally, it enhances graphics and simulations in virtual reality experiences, benefiting hospital-at-home knowledge repositories. Quantum computers are good at solving intricate optimization tasks and are efficient for inventory and supply chain management, route planning, resource allocation, logistics, financial portfolio optimization, and thereby cost reduction [8]. Furthermore, they improve risk assessment, financial decision-making, and payment flexibility [7]. They can break classical encryption, driving the need for post-quantum cryptography and secure data communication [8]. Quantum computing is in its early stage of adoption, with practical large-scale quantum computers still rare. However, ongoing efforts by researchers and organizations aim to enhance their power and stability. As this technology matures, it is expected to have a greater impact on industries in near future.

Nanomaterials infiltration to the Healthcare processes

Nanotechnology stands out as one of the fast-moving areas within contemporary science, showcasing its transformative potential across various sectors such as healthcare, defence, electronics, food production, chemical industries, energy, and numerous other scientific domains. The healthcare industry has experienced an increasing adoption of nanotechnology products, primarily because of the unique properties and functions that exceptionally small nanoparticles (NPs) and nanomaterials can exhibit. This development has paved the way for the creation of advanced nano systems aimed at diagnosing, imaging, and treating various diseases, including cancer, as well as diseases related to the cardiovascular, ocular, and central nervous systems [9].

Nanomaterials hold significant promise in the field of drug delivery. Tailored nanomaterials can transport medications, genes, or therapeutic agents to targeted cells or tissues, boosting treatment effectiveness while minimizing side effects. Such a targeted drug delivery model has been very effective in the cancer treatment and in nanoparticle-based vaccine delivery system where it allows for controlled antigen release while boosting immune responses. They support in

wound healing process by offering frameworks for tissue regeneration, managing infections, and delivering growth factors and help construct scaffolds. Also, nanoparticles can act as contrast agents in various medical imaging methods like magnetic resonance imaging (MRI), computed tomography (CT) scans, and ultrasound, and as nano sensors to selectively detect biomarkers and target agents, leading to earlier and more precise disease detection, identification, and monitoring.

Transformations or new advancements

Several modalities and approaches are foreseen to transform the next generation of healthcare:

Remote care enables virtual consultations, remote monitoring, and access to healthcare services from the comfort of patients' homes. Patients, closest ones or humanoid robots will constantly attend in care chain or its episodes. This trend is expected to continue and expand, especially in post-pandemic and shortening healthcare. The transition from paper medical records to electronic health records (EHRs) began in the 1960s. In the 21st century, cloud adoption is increasing, and most hospitals are transitioning to EHRs [8]. There is raising demand for next-generation EHR systems or ecosystems [10]. Regenerative medicine is moving closer to becoming a mainstream modality, with the potential to repair or replace damaged tissues and organs. Techniques such as stem cell therapy, tissue engineering, and 3D bioprinting will play a pivotal role.

Robotics in healthcare is evolving, with robotic surgical systems and telehealth robots improving surgical precision and enabling remote surgery. These technologies will become more sophisticated and widely adopted. Wearable devices, internet of things (IoT) sensors, and smart home health monitoring systems are becoming integral for continuous health monitoring, disease management, and lifestyle tracking. The next generation will offer more advanced sensors and seamless integration. Digital therapeutics involve the use of software-based interventions to treat medical conditions. They will continue to expand as standalone or complementary treatments for various health issues. Advances in biotechnology and gene editing, including clustered regularly interspaced short palindromic repeats (CRISPR) - CRISPR-associated protein 9 (CRISPR-Cas9), will enable precise gene therapies and the correction

of genetic disorders. The AI encyclopaedia of the world of biomarkers creates a new dimension of the human formulation at cell level. Healthcare professionals should also undergo regular training to stay updated on the latest technologies and best practices in patient care.

Overall, the disruptive innovations outlined in this section offer a promising trajectory for the evolution of hospitals and healthcare, improving patient outcomes and accessibility while advancing medical knowledge and practice.

The transformative technologies as described in the above section are influencing hospitals to adapt to the evolving needs. This section highlights the technological and infrastructural redesigning possibilities for hospitals and the potential impacts that can be achievable by 2040.

Hospitals are increasingly utilizing advanced technologies and data analysis tools which will help them optimize workflows and prevent bottlenecks. Following are some key areas where hospitals will be impacted through advancements in healthcare industry [Figure 2]:

Results

Figure 2: Illustration depicts some key potential impacts achievable by hospitals 2040

Patient centered care: Hospitals are becoming increasingly patient-centric focusing on meeting individual preferences and requirements. This shift is driven by a hybrid model that facilitates shared decision-making, individualized care plans and ensuring continuity of care. Empowering patients through education and shared decision-making ensures a more personalized and efficient healthcare experience, ultimately leading to improved health outcomes and increased patient satisfaction [11].

Remote shared care: Telemedicine also plays a key role in enabling remote interactions between patients and physicians through online consultations. Personalized health apps offer tailored health advice, medication management, and preventive care, empowering patients [12].

Personalized medicine: Today, it is extremely likely that advances in personalized care will raise the probability of a positive outcome after a surgery or medical treatment for any disease [13]. Personalized care driven by nanotechnology and genetic testing tailors treatments for optimal effectiveness and fewer side effects. Integration of wearable devices and IoT sensors simplifies health monitoring. Digital twin technology offers insights

into health and risks, enabling proactive interventions to prevent health issues.

24/7 Interconnectivity: Hospitals in the future will be well connected with 5G, cloud and equipped with IoT devices that enable real-time tracking and management of resources, including medical equipment, patient beds, supplies and all other resources. In supply chain management and logistics, quantum computers can be utilized which will lead to cost savings and enhanced efficiency. The hospitals are expected to have an interconnected ecosystem and dynamic environment by encouraging global collaboration, where the healthcare professionals enhance their collaboration by utilizing telemedicine, sharing knowledge, and engaging in research partnerships, ultimately leading to accelerated progress in medical science and expanded treatment possibilities [14]. Collaborations are strengthened through digital technologies, facilitating the rapid sharing of health data and best practices, aiding in addressing global health challenges.

Digital transformation//Boosting digitization: Incorporating comprehensive patient datasets, that includes genomics, medical history, and patient preferences, into a unified system like EHR systems will ensure seamless care delivery. In the

future, technologies like blockchain [15], and quantum computing [16] will gain more focus on securing patient data, ensuring privacy, data integrity, and secure sharing among healthcare providers while maintaining patient consent.

Automation and AI: Robotics and automation will be widely integrated into hospital workflows which will have a wide range of applications from complex surgeries to tasks such as medication dispensing, cleaning, and transporting supplies. Advanced robotics and AI will automate lab processes also. Administrative tasks that are automated will also be having a high impact in future. In clinical medicine, AI would aid in differential diagnosis [17], leveraging vast medical data to enhance accuracy and speed, reducing medical errors, and improving patient outcomes.

Smart Infrastructure and sustainability: Hospital facility layouts are moving away from rigid structures and are now being designed and refashioned to have more flexible structures and approaches to accommodate the evolving needs of healthcare. A flexible layout allows hospitals to respond efficiently to changes in patient volume, medical technology, and healthcare practices with a focus placed on environmental and occupational safety factors, operational expenses, institutional policies, and government regulations. Amid global challenges like the pandemic, designs must prioritize infection control and scalability. Green hospital practices, embracing quantum computing, and solar energy will reduce carbon emissions and enhance energy infrastructure [18]. Low-energy light emitting diodes (LEDs), occupancy sensors, and recycling initiatives further contribute to environmental conservation and cost efficiency. Hospitals that invest in adaptable layouts are better prepared to provide high-quality care while effectively managing resources, creating a more responsive and patient-centered healthcare environment.

Accessible healthcare: From a research-oriented hospital facility that prioritizes scientific innovation, conducting advanced research, clinical trials, and medical studies to enhance medical knowledge and develop new therapies, patients benefit from access to the latest treatments and medical technologies, making these hospitals hubs of medical excellence that not only provide top-quality care but also contribute significantly to the progress of healthcare on a global scale [19].

Cost effectiveness: Hospitals are poised to achieve cost effectiveness through cutting-edge

technologies and evolving trends mentioned above. These will enhance patient care and represent the future of economically sustainable healthcare.

Hospitals also need to stay up to date and are required to adapt their practices to align with regulatory compliances and ethical considerations to ensure patient safety, privacy, and overall well-being, which will not only safeguard the hospital's reputation and legal standing, but also underscore their commitment to delivering quality care within the boundaries of ethical and regulatory guidelines, which will uphold the trust of the communities they serve. The impacts discussed in this section not only enhance the quality of care but also represent a paradigm shift in the way healthcare is delivered as they hold the promise of elevating healthcare accessibility and elevating global patient outcomes.

In a nutshell, the optimized hospital workflows in 2040 will prioritize efficiency, patient outcomes, and a seamless patient experience while harnessing the power of advanced technologies and data-driven decision-making. These changes will help healthcare systems meet the evolving needs of patients and deliver higher-quality care.

Discussion

Looking ahead to 2040 in healthcare, especially for hospitals, the potential of what lies forward would transform care delivery. This paper has reviewed profound changes that hospitals are poised to embrace in 2040 which are not just random shifts, but are driven by dynamic technological advancements, evolving societal needs, and the economic landscape of the future.

At the core of this transformation will be the concept of patient centric care which is set to redefine how healthcare would be both delivered and experienced. Patients will have unprecedented access to their health information, fostering shared decision making with healthcare providers. Within a collaborative healthcare ecosystem, hospitals will work closely with various healthcare providers, fostering seamless coordination and information sharing. AI-driven diagnosis and treatment will augment healthcare professionals' capabilities, particularly in areas like radiology and pathology. This collaborative approach would ensure that patients receive holistic care that addresses their unique needs.

Hospitals will continue to reshape their workflow and care delivery methods by integrating innovations. The adoption of AI-driven differential diagnosis and decision support systems will enable faster and more accurate diagnosis. Along with this, personalized medicine tailored to an individual's genetic composition may also be seen optimizing the treatment plan and can minimize adverse effects. Hospitals may further diversify their offerings by incorporating complementary and alternative therapies, nanotechnology-based treatments, use of quantum computing, robotics, remote care, and telemedicine Integration.

With the increased reliability on electronic health records and interconnected medical devices, data security and patient privacy would be at the paramount. Hospitals must make substantial involvements in cybersecurity and explore disrupting solutions based on blockchain and quantum technologies to ensure secure patient information. Thus, strengthening patient information security will be a continuous effort to maintain stakeholder trust and collaboration.

It is also important for healthcare professionals and stakeholders to not only address these changes but also to adapt and thoroughly understand their impact, for which continuous training of healthcare professionals is crucial. Hospitals must have the responsibility to stay vigilant and be compliant with the evolving healthcare regulations and standards, adapting their practices to align with shifting laws related to data privacy, technology utilization, and patient care. All these proactive approaches ensure that hospitals are well-prepared to leverage and navigate the transformative medical advancements of 2040 and the potential to deliver quality medical services that will be more personalized, efficient, and accessible, contributing to improved global health outcomes.

Conclusion

The hospital landscape is rapidly evolving towards 2040, driven by technology and changing stakeholder needs. In order to maximise resource efficiency and sustainability, hospitals will include cutting-edge advancements like quantum computing, nanotechnology and digital twins. Patients will have more access to health information which will act as the foundation for collaborative healthcare ecosystems that would seamlessly coordinate with the help of AI-driven

diagnosis and treatment. Along with technological integration, consideration to data privacy and continuous development of healthcare professionals will be an integral part. Overall, hospitals will embrace global initiatives, leverage innovation and research, which will ultimately revolutionize healthcare for a brighter future in 2040.

Author contributions

SH has established and confirmed the paper's framework as well as guided and initiated the paper's context. UL has provided crucial insights and inspirations for the hospitals 2040 context. AG, JV, SP, NN, and JS collected the data, analysed the results, and added content to the whitepaper. All authors contributed to the paper's drafting and approved the final version. The authors do not state any competing interests.

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Disclaimer

This paper presents a general overview of hospital of the future only to emphasize its potential prospect. The scenarios and trends mentioned are based on the current knowledge and assumptions. Large language models were utilized for paraphrasing purposes and for guidance in certain sections.

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