Research Article

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Digital healthcare: A topical and futuristic review of technological and robotic revolution

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Abstract: Healthcare sector has become one of the challenging sectors to handle patient records as well as to provide better treatment to patients within a limited period. Covid-19 also exposed the limitations of the healthcare system due to the lack of better services. So, the involvement of information and communication technologies (ICTs) with the healthcare sector brings radical changes at global as well as local levels such as in hospitals and dispensaries. The article enlightened a novel survey technological paradigm that helps to facilitate the digital healthcare. With the use of technologies, the healthcare sectors are becoming more digital, innovative, patient-centric, and more effective. This article explores the proposed technological developments such as real-time health monitoring, generation of electronic health records, patient health record, mhealth, robotics, as well as robot sensors that are associated with healthcare sectors. This article also highlights the role of ICTs in different healthcare-related fields such as education, hospital management, health-related research, and data management as well as lightening the delivery levels of healthcare services. The article deals with the robotic applications in the healthcare field. This article categorizes the technologies as current and futuristic technological innovations enabling healthcare-as-a-service with benefits.

Keywords: artificial intelligence, big data, cloud computing, information and communication technology, internet of things, neural network, robotics, robot sensors

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1 Healthcare sector and digitization

Healthcare is emerging as a prominent area bothering humankind. With the advancement of information and communication technology (ICT) sector and advent of virtualized infrastructure, the medical sector is focusing on making healthcare delivery not just confined to the medical stores and hospitals but more virtual in nature. The healthcare delivery by the health-oriented organizations has become digitally innovative post acquisition of ICT technologies. Digital healthcare or technology-enabled healthcare is not only offering real-time on-home healthcare services to the patients [1–4] but also facilitating remote healthcare monitoring operations. Many advanced devices have emerged within the healthcare industry including wearables and sensor devices as well as multi-robot systems for healthcare, from genomics to personalized medicine etc. that assist in diagnosis as well as prediction of diseases [1,5]. The novel devices and applications have entered into the healthcare sector, from wearables to genomics to personalized medicine, that aid in disease diagnosis, their prediction, management, and treatment [6].

In this increasingly connected world and with the ubiquitousness of data collection, the healthcare sector is using advanced analytical techniques to optimize patient care and doing so in a cost-effective manner [5]. Healthcare also overcomes geographic limitations. The advanced and latest technologies provide the facilities to communicate with people and doctors all over the world as virtual teams and also provide support for shifts such as from medical centric to patient centric and further consumer centric [7].

The integration of ICTs with the healthcare sector has brought drastic change at global as well as local levels. Healthcare sector is greatly impacted by digital information technology (IT) paradigms such as Internet of Things (IoT), big data, cloud computing and other futuristic technologies such as robot intelligence, big data analytics for robotics, robot digital twins, artificial intelligence (AI), smart robotics, and cloud robotics. Before the amalgamation of ICT technologies in healthcare, there were numerous challenges in this field but now the healthcare sector is highly

dependent on the advancements in technologies. The primary advantages observed in the healthcare sector upon union with the IT sector include reduction in communication gap which is now at level 0 in addition to easier information accesses and provisioning of improvised healthcare facilities such as room preparation for patient treatment with the support of robots.

2 Novel contributions of the review

The article presents a novel review of digital healthcare primarily focusing on the technological paradigms that facilitate its delivery. As technology and digitization are increasing, so are the associated implications for them in different sectors. The technological revolution has led to significant changes in the delivery and consumption of healthcare sector. The latest technologies such as robotics, big data, and machine learning are gaining momentum in particular for their use in healthcare provisioning. There are previous reviews pertaining to digital healthcare [1–3,6,8,9–17]. However, the focus of such reviews is more specific on patient record handling, security, privacy, electronic health record (EHR), and healthcare whereas the review presented in this article highlights the role of various technological innovations that are being increasingly implemented for providing healthcare. The article reflects the role of such latest innovations in facilitating digital healthcare. Also, the article analyzes the existing frameworks based on different and latest technologies for supporting endowment of digital healthcare.

The article has been organized into different sections. Section 2 highlights the benefits of ICT in the healthcare sector and associated fields for provisioning of digital healthcare. Section 3 enlightens the technological paradigm and benefits in the healthcare sector that underlie the digital healthcare. Conclusively, Section 4 discusses the role of post-Covid healthcare provisioning revolution.

2.1 Digital healthcare-related fields

With the involvement of ICT in healthcare, it has become easy for doctors, caregivers, dispensaries, and public healthcare sectors to provide better facilitation and treatment, and the communication level also has been enhanced between patients and doctors. The benefits of ICT [8] are categorized into four main healthcare-related fields as shown in Figure 1.

The healthcare sector is becoming efficient and providing better job opportunities due to better technology-enhanced education. There are three components creating a link between healthcare and education. The first component is better health opportunities such as income/resources by creating better job opportunities and high-level earnings that promote benefits in terms of health insurance or earned leaves or retirements, social and psychological benefits such as less stress level, health behaviors, and healthier neighborhoods. Higher earning people can take benefits of a good diet, get better health-related facilities, and better transport facilities. The second component is reverse causality, which means poor health can put education at risk by learning disability and burden of attendance. The third component is contextual factors such as policies related to social and family characteristics that affect education and health [18].

The involvement of ICT in healthcare has brought the greatest impact for management in the healthcare sector. ICT provides better safety for patients, improves the

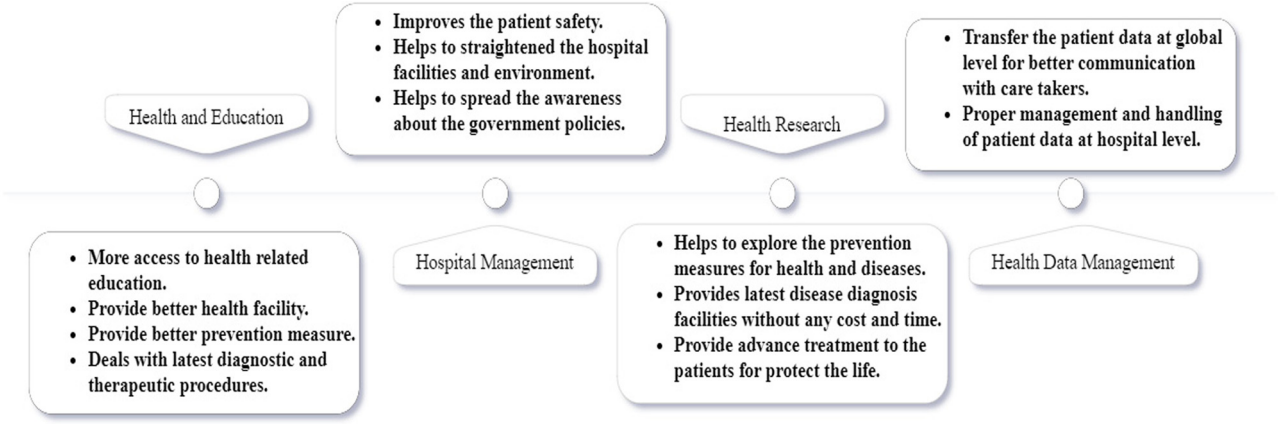

Figure 1: Digital healthcare-related fields.

diagnosis, and prevents diseases from spreading [19]. ICT helps to store patient records in electronic form and generates the EHR that can be accessed globally. ICTs in healthcare sectors provide better care quality, security and privacy, and managed health services such as electronic medical record (EMR), EHR, and patient health record (PHR).

ICT promotes the healthcare sector with tools and innovations to monitor patient's health. The healthcare sector has become digital healthcare with the involvement of digital technologies such as telehealth, wearable medical devices, telemedicine, sensors, robotics, EHR, EMR, and mhealth [8].

Technologies provide a way for the healthcare sector to efficiently manage the usage and access to the patient data at the local and global levels [8].

2.2 Benefits of ICT in healthcare sector

The latest facilities in the healthcare sector due to the involvement of ICT are EHR for providing the patient's history to provide better treatment. Due to the involvement of ICT in the healthcare field, it is also termed as health IT that affects the healthcare center's operations. There are plenty of benefits associated with healthcare sectors which are as described as follows:

- **Increased patient safety:** Due to ICT, healthcare provides a better communication facility between clinicians and patients; reduces errors in the potential medical sector; and encourages patient-centric care that increases the safety level of patients [9]. The EHR factors were introduced to handle errors and maintain PHR. There are various technologies to reduce errors and improve patient security such as medical alerts, clinical flags, and reminders.
- **Efficient care coordination:** ICT helps in the service delivery improvements between the health service coordinators and patients for facilitating effective care as well as efficient adoption of healthcare practices. The various key principles are incorporated with healthcare to provide effective care coordination, enhance the interoperability, and enable patient-centered care and transition care [10].
- **Enhanced performance analysis:** IT has brought a positive impact on healthcare sectors. Performance analysis of the healthcare field is improved with the involvement of technologies, and the healthcare field has become more developed and upgraded [10]. Now, it is easier to access medical information. Technological innovation in healthcare has improved expectancy as well as quality of life.
- **Reduced operational cost:** Due to the involvement of advanced technologies, operational costs and labor costs have reduced in the healthcare sector [11]. There are five ways that help to reduce the operational costs such as incurring low administrative expenditures; cutting the specialists' needs; elimination of hospital rooms expenses; less hospital staff which further lowers the staffing costs; and reduction in the streamline processing costs.

3 Technological paradigms underlying digital healthcare

Today, technologies have brought drastic changes in the field of healthcare structure and healthcare services, such as upgraded treatment and flexible preventive techniques. Subsequently, the healthcare sector has witnessed exponential growth after integration of digital technologies into it. It has been observed to be more digitized and modernized. A large number of digital collaborations in the healthcare sector have been observed. These can be categorized into current and futuristic technologies that have been discussed in the following subsections.

Figure 2 reflects the transformation phases involved in the healthcare sector toward digital healthcare. The transition can be divided into three different phases involving the development and evolution of emerging technologies [20].

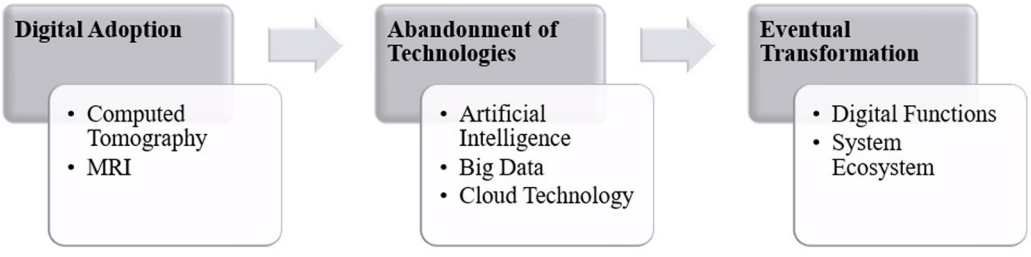

Figure 2: Technology involvement phases in digital healthcare.

In the first phase, new technologies and tools and services such as tomography and magnetic resonance imaging (MRI) are adopted in the healthcare. In the second phase, various technologies are augmented to replace the older technologies with updated ones such as AI, big data, and cloud computing. In the subsequent and third phase, the digital systems are incorporated with healthcare to provide better services to the patients. Sections 3.1 and 3.2 summarize the current and futuristic technological innovations enabling healthcare-as-a-service (HaaS) in detail.

3.1 Current technological innovations enabling digital healthcare

In the twenty-first century, the healthcare industry is transforming as a more innovative industry and fulfilling the demand of patients and providing better services. As a result, the healthcare sector has become digitally transformed healthcare. Due to the advancements in the technologies in the healthcare market, healthcare has also become patient centric. The patients require on-demand healthcare facilities owing to the facts that 52% healthcare-related browsing is feasible through mobile phones, 2.7 billion people have access to mobile phones, and 77% patients use smartphones to book appointments to get better healthcare services [21]. Figure 3 shows the latest technologies that have emerged with healthcare sector and further subsections elaborate the role of these technologies.

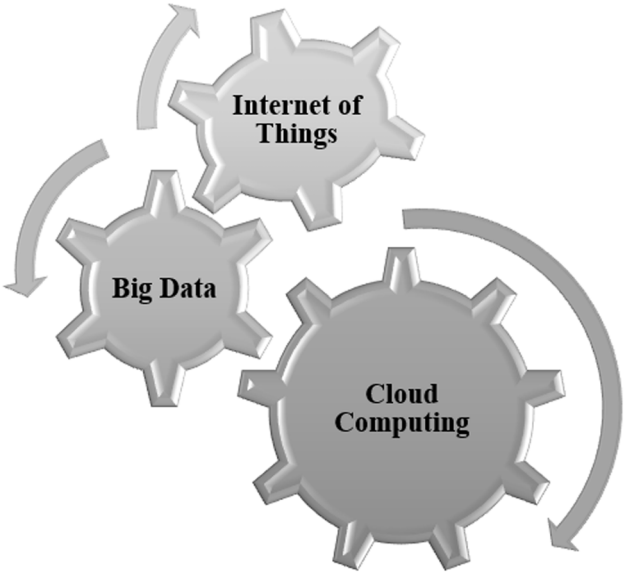

Figure 3: Current technological innovations enabling digital healthcare.

3.1.1 Cloud-supported digital healthcare

Cloud computing is one of the vast technologies used in every industry for better services. Cloud computing helps to increase efficiency and reduce cost. With the help of cloud computing, it has become easier and safer to share patient's records, automate backend operations, and develop mobile applications facilitating digital healthcare. The cloud facilitates everything as a service model. Thus, digital healthcare is also delivered as services. It is estimated that by the end of 2030, almost 95% applications will be embedded with cloud computing [22]. In the healthcare sector, data are almost transmitted, stored, and retrieved electronically with the help of ICT. The various healthcare-related technologies are integrated such as [23–25] EMR, computerized physician detail entry, telemedicine, smart card, EHR, and digital images [26].

Cloud computing as a service model provides the facility of hand-on-hand services for patients and staff. The benefits of cloud computing in healthcare sector are depicted in Figure 4.

The figure depicts the personification of cloud computing in the healthcare sector to provide better health-related services and storage of data at a global level. Handling large amounts of data is more challenging in the healthcare sector. In order to deal with such issues, cloud computing offers storage-as-a-service (SaaS). Cloud data storage enables storage frameworks such as HDFC, Hive, and HBase to store and secure the data for ease and flexible management of the data that can be accessible 24 × 7 at a global level. As a result, it becomes easy for physicians to share the data with other clinics for better decisions. Cloud storage provides backup facility on a

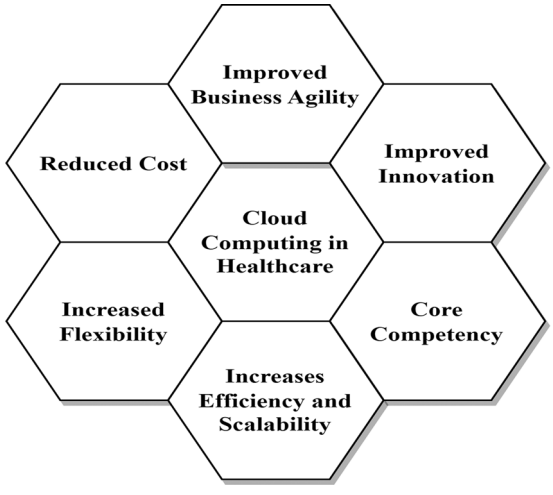

Figure 4: Cloud computing benefits in digital healthcare.

Table 1: Proposed healthcare frameworks based on cloud computing supporting digital healthcare

Ref no	Key-objectives/goals	Implemented technique	Tool(s) used
[28]	For eczema disease detection which is one of the skin allergies	Genetic algorithm	Backpropagation neural network
[29]	Diabetes disease detection	Support vector machine (SVM), K-nearest neighbor (K-NN), decision tree (DT), naïve Bayes (NB)	JAVA Programming and Amazon Cloud
[30]	For ECG monitoring and analysis	Signal-matched filters, neural networks, time frequency decomposition methods, genetic algorithms	JavaTM", Techniques of HTML, jQuery, AJAX, and java server pages
[12]	Fitness diagnosis	Discriminate analysis, naive Bayes, and KNN	XML/JSON
[31]	Coronary heart disease	Predictive algorithm	Raspberry Pi microcontroller
[32]	Heart disease	SVM, J48, NB, multilayer perceptron (MLP), random forest, AdaBoost, boosted tree	WEKA and R
[33]	Diabetes diagnosis	Fuzzy logic and uncertainty factors	API (java) Cloud Server, VMWare
[34]	Breast cancer diagnosis	daBoost, SVM, naïve Bayesian, perceptron, and KNN	Amazon EC2, Wekaver. 3.8
[35]	Heart disease prediction	Supervised machine learning	MATLAB 2019
[36]	Breast cancer prediction	Fuzzy logic, supervised machine learning	MATLAB R2019a

regular basis. Cloud computing also offers better opportunities for the doctors as well as hospitals for patient engagements and accessibility of records at a global level.

In order to provide in-house patient services and cost-effective provision, various researchers have already proposed various platforms and frameworks that facilitate digitized healthcare. A range of frameworks and platforms that support digital healthcare based on cloud computing have been proposed and are discussed in Table 1.

3.1.2 IoT-supported digital healthcare

IoT defines the interconnection of billions of devices throughout the internet that are collecting and sharing patient data. Specifically, IoT provides the provision of implantation of various devices ranging from sensors to smartphones and wearable devices with the patient body. When these devices are connected with an automated system, it becomes easy to collect the required information, analyze, and take action to provide better treatment to the patient in real time. IoT as a technology provides better opportunities for building the standards that are useful for exploring the work to be done, time efficiency as well as money saving [13]. IoT provides real-time patient monitoring, diagnosis service with the help of sensors, robotic sensors, and IoT devices.

As per the survey, it is estimated that 99% organizations will adopt IoT-based technologies by 2025. IoT devices were valued at USD 28.42 billion in 2015 at a market level whereas it is expected to be increased to USD 337.41 billion in 2025 as per their betterment. Involvement of technologies in the healthcare field improves quality of life and uplifts treatment efficiency by facilitating HaaS with various benefits [27] that are given in Figure 5.

IoT technology helps to monitor patients accurately by minimizing the risk of errors.

Additionally, real time patient's data is monitored for observation that improve the patient's treatment services. Involvement of IoT in healthcare has decreased the visits to doctors and room-booking cost in hospitals as diseases can be observed in advance based on symptoms and better treatment can be provided as per the collected data that are real and accurate after patient monitoring. IoT devices will alert the doctors and clinics to take proactive action by real-time monitoring. Currently, the healthcare sector with IoT providing real-time monitoring of the patient as well as

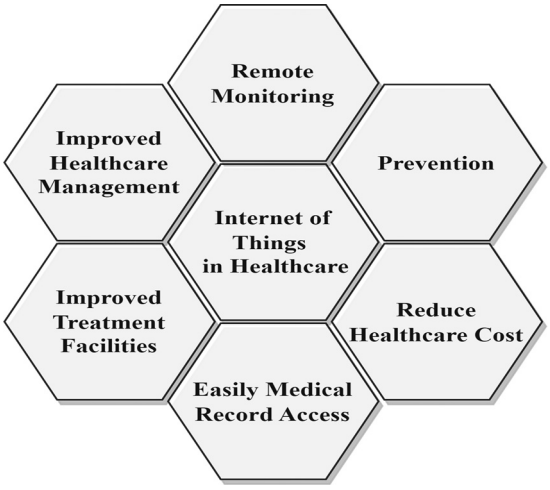

Figure 5: IoT benefits in healthcare.

detection and diagnosis of the diseases with the help of various methodologies that have been proposed based on IoT to support HaaS are discussed in Table 2.

3.1.3 Big data-supported digital healthcare

What is the role of big data in healthcare? How does it help to analyze patient records? How is it changing the healthcare landscape? The main motive of big data is how to keep the data to provide the analysis to the patients. Big data supports the healthcare sector with the use of descriptive, prescriptive, and predictive analytics to get the insight of the data [37]. Big data in the healthcare sector supports threefold [37] augmented digital healthcare that are as follows:

1. To improve the clinical outcome with patient data.
2. Workforce productivity is boosted by leverage data.
3. Healthcare financial data are used to improve the revenue stream of hospitals, organizations, etc.

Notably, the complex and massive data are time-consuming as well as expensive to analyze. Big data helps the Health Professionals to drive and provide the decisions and solutions for better treatment, and big data dominates patient's outcome by providing the various benefits [38] as shown in Figure 6.

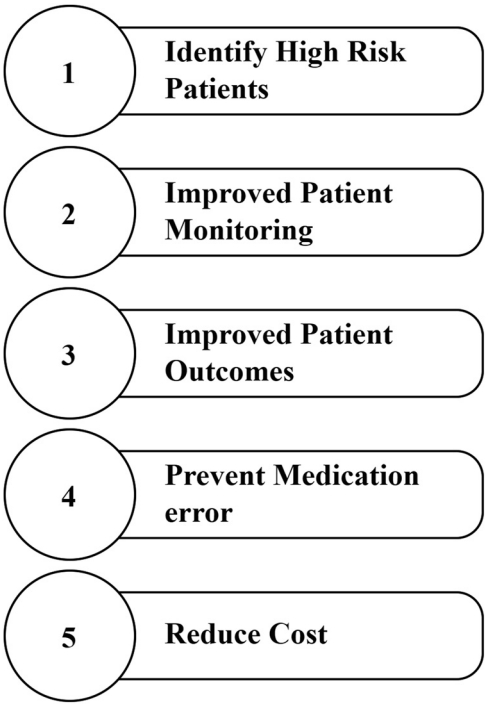

Figure 6: Big data benefits in healthcare.

Table 2: Proposed healthcare frameworks based on IoT supporting digital healthcare

Ref. No.	Key objective/goals	Implemented technique	Tool(s) used
[14]	To measure heart activity	Heart attack prediction	ECG sensor
[39]	To analyze the human motion	Health monitoring	Vision-based sensor
[40]	To detect diseases such as infectious and heart-related disease	mhealth disease diagnosis system	MySQL
[15]	To provide the security for body sensor network healthcare system	Patient monitoring	Sensors such as EEG, EMG, BP, FCG, and motion
[41]	To measure the blood pressure, heartbeat, and temperature	Diseases detection	Microcontroller ARDUINO and sensors
[42]	To monitor health conditions of stroke patients	Health monitoring	Arduino Mega microcontroller, pressure sensor, heartbeat sensor, sugar sensor
[43]	To predict the patient's health condition based on stored data in a database.	Health monitoring	Arduino, E-Health sensor (body temperature and ECG)
[44]	To maintain the patient's physiological parameters and activity in the hospital	Patient's health monitoring	Sensors (body temperature, pulse rate, acceleration), microcontroller
[16]	To minimize patient's health risks	Remote monitoring of patients' health	Piezo sensor and Temp sensor, Arduino, Raspberry Pi
[17]	Monitoring of heart rate, blood pressure, respiration rate, body temperature, body movement, and saline levels	Remote monitoring of health	Raspberry Pi
[45]	Monitoring of patient health based on various diseases	For monitoring of heart diseases, breast cancer, diabetes, spect heart, thyroid, dermatology, liver disorders, and surgical data	K-NN, SVM, DTs, random forest, and MLP

Table 3: Proposed healthcare frameworks based on big data that support digital healthcare

Ref. No.	Key objective/goal	Implemented technique	Tool(s) used
[48]	To predict the heart disease	Naive Bayes algorithm	Hadoop and Apache spark
[49]	To predict the heart disease	Random forest, naïve-Bayes classifier	Apache Spark, Hadoop
[50]	Heart disease prediction	Feature selection, DT, SVM, random forest, naive Bayes, K-NN	R studio
[51]	Covid-19 diagnosis	Big data analytics	NVivo 12 and VOS viewer
[52]	Disease diagnosis	MAPREDUCE (), k means	Hadoop, HDFS
[53]	Random forest	Heart disease detection	Apache Spark, Cassandra
[54]	DT, J48	COPD prediction	WEKA
[55]	Predictive analysis	HIV AIDS detection and prevention	R programming
[56]	NB, DT and ANN	Heart attack prediction	Hadoop
[57]	lambda feature, clustering, SVM	Heart attack prediction	Apache Spark, Cosmos DB
[58]	Crow search algorithm, BSO algorithm	Heart disease and multi-disease diagnosis	MATLAB

Healthcare organizations are monitoring the patient data using sensors such as wearable technologies (watches) on a regular basis. The monitored data are used to predict the patient's health, detect blood pressure and glucose level, provide better treatment, and track the patient monitor. Big data technology in the healthcare sector is one of the cost-effective technologies that helps to save money and provide better services to the patients. Additionally, big data helps in reduction of errors. Big data analytics helps to improve patient outcome to provide them access to their medical records and also improve their treatment quality.

With the help of big data tools, caretakers also can provide other information such as staff schedule, their availability, patient appointment time, and medical insurance data, and advanced real-time benefits are provided with various proposed frameworks and models that are associated with big data for supporting digital healthcare as discussed in Table 3.

3.2 Futuristic technological innovations enabling digital healthcare

The healthcare sector is changing with the involvement of technologies. It will bring significant changes in the healthcare sector to provide HaaS. The various advanced technological developments include 3D printing, remote diagnosis, and virtual and augmented reality. The different latest technologies involved in the healthcare sector include machine learning, robotics, deep learning, AI, blockchain, and neural network. Figure 7 discusses the futuristic technologies enabling digital healthcare.

What actually is going to happen in the future with the healthcare sector? How will it be more interactive instead of technological enhancement? What will be involved to make it more interactive [46]? Why will it be a breakthrough in future? Despite the facts, it is not easy to predict the answers to the aforementioned questions but we can observe the impact of technologies in the healthcare sector as discussed in further subsections.

3.2.1 Machine learning-supported digital healthcare

Machine learning plays a crucial role in the healthcare sector and provides different ways to analyze the data. It is observed that Google has developed machine learning algorithms to predict cancerous tumors using which skin cancer can be predicted as observed by Stanford [47]. Machine learning facilitates the sector to become better decision makers by generating accurate insights and streamlining delivery services; advanced benefits [47] are incorporated into the healthcare field as shown in Figure 8.

How does machine learning help patients and doctors in healthcare for predicting and diagnosing diseases?

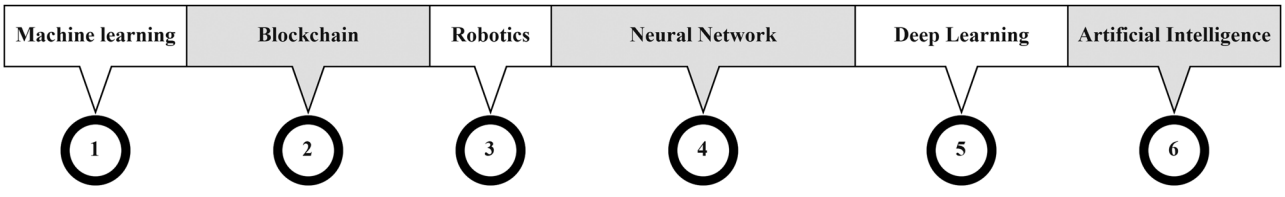

Figure 7: Futuristic technologies enabling HaaS.

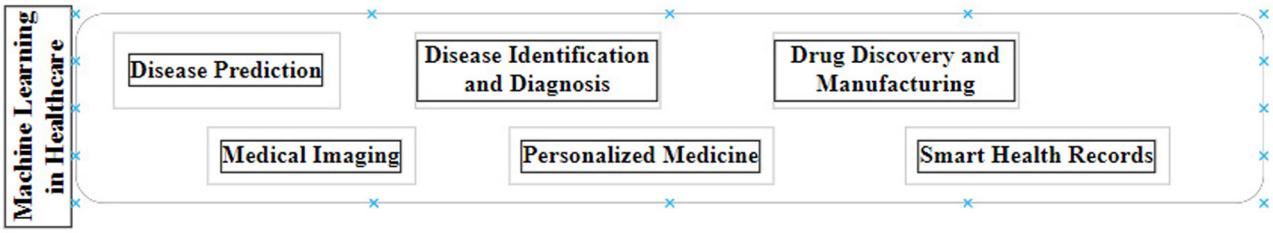

Figure 8: Machine learning in healthcare sector.

Machine learning methodologies in the healthcare sector help to predict diseases based on major symptoms and effects on the human body, and the caretaker can easily perform analysis on accurate data. Such data are collected through machine learning tools by remote monitoring of patient health. Remote monitoring provides better services for drug discovery and medical imaging such as X-Ray, MRI, and CT-SCAN [47]. Machine learning enhances the services for screening and diagnosis with the advanced frameworks and models that are being proposed by the experts. Table 4 discusses the existing proposed frameworks and models associated with machine learning to support digital healthcare.

3.2.2 Blockchain-supported digital healthcare

In the healthcare sector, blockchain has become one of the secure databases as well as an example of decentralized innovation. The healthcare sector has become more revolutionized and transformed with the advent of blockchain technology. As per the survey, it is estimated that the global blockchain healthcare industry will be increased by $500 million before the end of 2022 [59]. Blockchain helps to shape the healthcare sector by providing various benefits such as smart health records, security, and protection. Few of the benefits are shown in Figure 9 and are discussed further in this section.

How is the blockchain beneficial for healthcare databases? How does it provide efficient services? With blockchain technology, the quality of the care and services given to the patients have improved. Also, the patient data has become more secure with the use of bitcoins [59]. Blockchain provides the provisioning of management of EMR, EHR, and PHR in ledger [60]. The rapidly growing blockchain technology provides healthcare a fertilized ground for experimenting and testing with proposed and experimental frameworks. Some of the proposed frameworks associated with blockchain that support digital healthcare are discussed in Table 5.

3.2.3 AI-supported digital healthcare

AI is bringing a drastic change in the healthcare sector. The lives of patients, doctors, nurses, caretaker, and administrative staff have become easy with the introduction of AI in healthcare fields. As per the given data, it is estimated

Table 4: Proposed healthcare frameworks based on machine learning that support digital healthcare

Ref No.	Key objective/goal	Implemented technique	Tool(s) used
[61]	To analyze coronary artery disease	DT and pruned C4.5	Weka
[62]	To predict and classify heart disease	Random forest, logistic regression and artificial neural network	R-programming
[63]	Thyroid cancer detection	Relief feature selection	MATLAB
[64]	COVID-19 Prediction	SVM	MATLAB 2019
[65]	Prediction of diseases	KNN and Convolutional neural network (CNN)	NetBeans and MySQL
[66]	Heart disease prediction	NB, neural network, DT, KNN, random forest	WEKA
[67]	Diabetes and hypertension	Ensemble learning	iForest, SMOTE Tomek
[68]	Heart disease prediction	J48, Bayes Net and naive Bayes, simple cart and REPTREE	WEKA
[69]	Prediction of chronic disease	Stochastic gradient descent algorithm, CNN-based unimodal disease risk prediction, naive Bayes, KNN and DT	Big data analytics
[70]	Diagnosis of diabetes	Artificial neural network, NB, DT	A fuzzy inference system

Figure 9: Blockchain in healthcare.

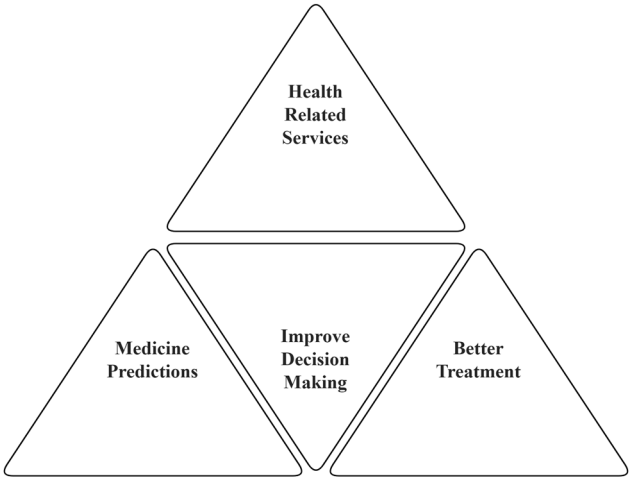

Figure 10: AI in healthcare sector.

that till the end of 2026, around $150 billion will be provisioned for AI in medical fields in high-growth countries. AI brings upliftment [71] in the healthcare sector as shown in Figure 10.

AI is reshaping and reinventing the healthcare sector by providing services related to health sectors such as immediate access to the patient records, patient safety, and medication to patients. Patients can easily communicate with the team. Healthcare-related services such EHRs are spreading across hospitals and clinics at global level. For the treatment, AI helps to predict the diseases and diagnose it with medical prescription. Further, AI also facilitates doctors and professionals to make decisions efficiently for better treatment. AI-related research is in progress in healthcare-related fields for reinventing the healthcare sector. Various methodologies have been proposed with AI that support HaaS that has been discussed in Table 6.

3.2.4 Robotics-supported digital healthcare

In the hospital, robots are playing an important role in performing medical precaution to routine tasks [72]. Robots are specialized as human beings to provide treatment-level services to provision HaaS. As reported by Credence Research, in the medical industry, robots will be increased with an additional increase rate of $2 billion by the end of 2023 as it was only $8 billion in 2015. Robots are being developed in the healthcare field to perform various roles that are specialized in different facilities such as neurology; the roles of few of the robots are shown in Figure 11.

How are the latest innovations being introduced in the healthcare sector? Why are these required? What improvements have been made with robotics in the healthcare sector? With robotics in the healthcare sector, human interaction has been reduced and as a result patient diagnosis and treatment have become efficient and accurate. With the robots, patient surgery has become an easy task and it saves time compared to a manual assistant and provides the fastest recovery facilities and treatment. Robotics has become an indoor navigation facility to transport medicine at patient location and also helps in room disinfecting [73,74].

Robotics helps in reinventing the healthcare sector by providing various proposed frameworks which are discussed in Table 7.

Table 5: Proposed healthcare frameworks based on blockchain that support digital healthcare

Ref. No.	Key objective/goal	Implemented technique	Tool used
[75]	Diabetic-cardio disease prediction	Rule generation, clustering, feature selection	Java
[76]	Healthcare and fitness data management	Conventional byzantine fault tolerance algorithms	Ethereum blockchain
[77]	Medical data access and permission management	Data mining	Blockchain

Table 6: Proposed healthcare frameworks based on AI that support digital healthcare

Ref. No.	Key objective/goal	Implemented technique	Tool used
[83]	Diagnosis of breast tumor in ultrasonic images, ovarian cancer, and heart sound diagnosis	ID3, C4.5, and CART algorithms	Weka tool
[84]	Neonatal disease diagnosis	Genetic algorithm	Neuro intelligence
[85]	Heart disease diagnosis	Generalized regression neural network (GRNN)	MATLAB

Figure 11: Robotics in healthcare.

Table 7: Existing proposed healthcare frameworks based on robotics that facilitate digital healthcare

Ref No.	Key objective/goal	Implemented technique	Tool(s) used
[86]	Parkinson's disease prevention and diagnosis	Device sensing	MATLAB R2018b

Robotics has brought about a significant change in the healthcare sector in providing digital healthcare [78]. Medical robots help the caregivers to provide better treatment, medical facilities for patients as well as they are brining surprising advancements and innovation in the healthcare field. Additionally, robots reduce the burden of healthcare professionals by providing the automation routine of daily activities. Moreover, robots also help the healthcare organizations in case of shortage of staff such as doctors, nurses, and caregivers [79]. In medical laboratories, robots deal with range of tasks from simple tasks to complex surgeries. Robots help the patients in physical therapy and deal with the rehabilitation of patients [80].

Robots also play different roles in the healthcare field such as data collection and processing and patient health monitoring. Robotic machines provide the privacy and security for managing health data and also improving efficiency and data optimization [79].

Different types of robots used in healthcare sectors are ARMAR III, Care-O-Bot 3, Cody, PR2, RIBA, robotic nursing assistant, hair-washing robot, ASIMO, and ROSE, which provide healthcare facilities for better treatment and supportive care [81].

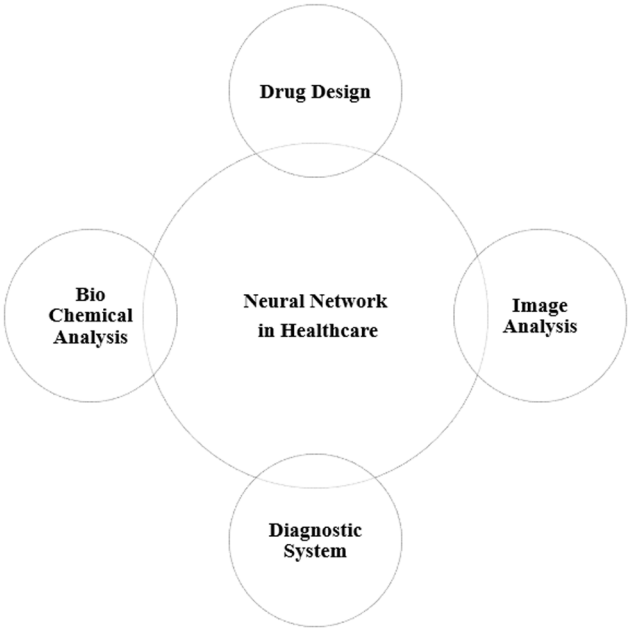

Figure 12: Neural network in healthcare sector.

3.2.5 Neural network-supported digital healthcare

Neural networks are a futuristic technology in the healthcare sector that is changing the diagnosis system of the healthcare industry. Neural networks will enhance the clinical documentation accuracy such as EHR [82]. Neural network provides in-house treatment facility for disease prediction and diagnosis for better health management. A few of the benefits of neural network are shown in Figure 12.

Table 8: Proposed healthcare frameworks based on neural network that support digital healthcare

Ref. No.	Key objective/goal	Implemented technique	Tool used
[92]	To detect diabetic retinopathy	Medical image processing	CNN, fundus
[93]	To detect glaucoma, diabetic retinopathy tumors, interstitial lung diseases, heart diseases, tuberculosis, and covid-19	Image analysis	CNN
[94]	To classify pneumonia based on chest X-ray dataset	Medical image classification	CNN
[95]	Covid-19	Chest X-ray images	CNN, residual networks
[96]	Parkinson's disease diagnosis	ANN, random forest, SVM, XG-boost, KNN	Google colab python notebook
[97]	Diagnosing diabetes type II	J48, NB, RBF	MATLAB
[98]	Diabetes prediction	Back-propagation training algorithm	JNN
[99]	Prediction of diabetes mellitus	Levenberg–Marquardt training algorithm	MATLAB R2017a
[100]	Prediction of diabetic type 1	Optimized nonlinear autoregressive neural network	Automatic insulin delivery advisor simulator

How impacting the neural network is in the healthcare field? What methods are used for analysis of dataset? Neural network provides disease diagnosis using image analysis methods that provide an accurate diagnosis system for diseases. It also helps in chemical analysis and drug discovery. Based on neural network [87], various frameworks have been proposed that are being used to facilitate HaaS. A few of the frameworks are discussed in Table 8.

3.2.6 Deep learning-supported digital healthcare

Healthcare industry has adopted the latest technologies to provide digital services. Deep learning is one of them that plays a prominent role in the healthcare industry. It becomes easy to collect the patient's medical reports and health records to make an appropriate diagnosis for the patient [88]. Deep learning provides an intelligence system-based framework to facilitate HaaS. The applications [88] of deep learning in healthcare field are shown in Figure 13.

Based on these benefits, various platforms have been proposed to enable HaaS. A few of them are highlighted in Table 9.

4 Digital healthcare revolution post-Covid

Digital revolution has become one of the urgent requirements in the healthcare industry due to the recent Covid-19 outbreak [89]. ICT has brought about a drastic revolution during the Covid-19 pandemic due to which different sections were affected such as individuals, non-profit organizations, and government institutes at a global level. There are various arguments [90,91] related to this crisis as mentioned in the following:

- What is the role of ICT at a global level?
- How is ICT affecting social life by maintaining the balance between control, autonomy, and power shift?
- How does practical and theoretical evaluation depend on the healthcare crisis due to Covid-19 [90]?

4.1 ICT at global level

During Covid-19, ICT at a global level contributed toward the healthcare field by maintaining the distance, improving the

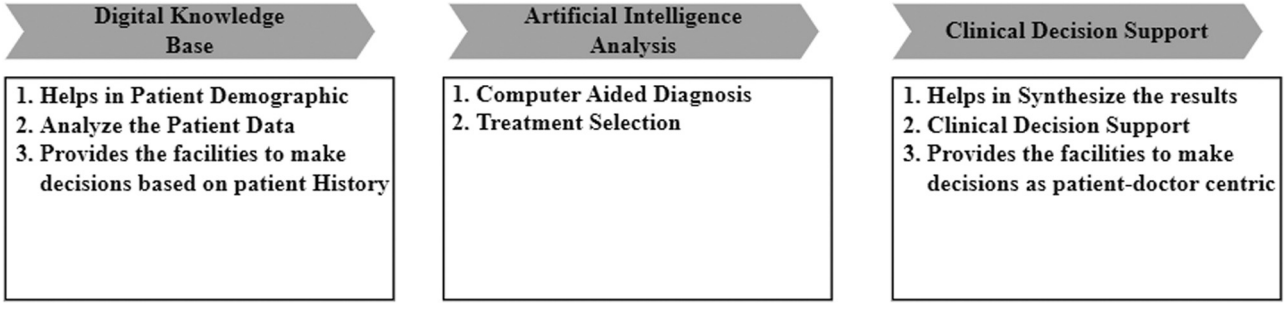

Figure 13: Deep learning in healthcare.

Table 9: Proposed healthcare frameworks based on deep learning that support digital healthcare

Ref. No.	Key objective/goal	Implemented technique	Tool used
[101]	Diagnosis of heart diseases	Ensemble deep learning	Gateway devices (mobile phones, laptop, and tablets), sensors, Python,
[102]	Heart disease prediction	SVM, logistic regression, MLP, random forest, the DT, and NB	Protégé OWL, WEKA, JAVA
[103]	Cardiovascular disease prediction	SVM, KNN, DT	TensorFlow
[104]	Diabetes prediction	DT, naive Bayes, artificial neural network, and deep learning	Rapid miner
[105]	Louvain clustering, manifold learning, and hierarchical clustering	Diagnosis of dengue fever, diagnosis of Covid19 and other infectious diseases	Orange
[106]	Covid-19 detection	Voting-based approach and a cross-dataset analysis	TensorFlow/Keras framework, Python
[107]	Diagnose of covid-19	VGG19, DenseNet-201, InceptionV3, ResNetV2, InceptionResNetV2, Xception, and MobileNetV2	Python and the TensorFlow 2 Keras
[108]	Lung abnormalities	SVM, Alex Net, VGG16, VGG19, and ResNet50	MATLAB

quality access of medical record, and maintaining reports such as EHR, EMR, and PHR. It brings innovation in healthcare in the form of digital healthcare to manage the exchange of patient information among individuals or stakeholders such as government, doctors, healthcare agencies, patients, data administrators, and insurance companies. ICT as a tool in healthcare provides prevention, diagnosis, treatment, and health monitoring services to handle issues related to health. The Covid-19 outbreak forced many countries to adapt the latest trends in ICT for better services [1].

4.2 ICT in life balancing

During Covid, life had been balanced due to the involvement of ICT in the healthcare sector. ICT maintained social connectivity by virtual meet to reduce the risk of diseases. Digital healthcare provides easy access to patient data for their betterment and to improve their quality of life. Without wasting time, patients can get better treatment facilities at their own pace. ICT involves real-time monitoring services such as health monitoring and telehealth services [90].

4.3 Healthcare crisis

Due to Covid-19, the burden on healthcare professions has been increased. But innovation in technologies has brought the change as the healthcare sector was facing crisis such as loss of income opportunities and global health-related services. Due to the involvement of the technologies, any individual can access patient record as on-line service to provide them better treatment, and reports are saved in the form of HER, EMR, and PHR in the cloud that can be accessed from anywhere. ICT involved telehealth, telemedicine, remote monitoring, and e-health services to overcome such crisis.

5 Conclusion

With the advent of technologies, the health sector has become a reinvented field that provides remote monitoring and real-time health diagnosis methods. Various technological advancements have been made in the healthcare sector, and it is predicted that in future more technologies will be involved to provide HaaS. Technologies have brought the change in healthcare field with amalgamation of various technologies such as big data, cloud computing, IoT, blockchain, machine learning, and neural networks. This article highlights the benefits of technologies in various fields such as education, research, healthcare sector, and management data; also, in the article, detailed survey has been conducted in the field of healthcare. A systematic survey has been conducted related to role of technologies in healthcare sector that are classified as current and futuristic technological innovations. The article concludes with significant recommendations for the latest technologies that are and will be futuristically beneficial for facilitating digital healthcare.

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References

[1] K. Milioris and K. Papageorgiou, "A study of healthcare ICT systems and their usefulness during Covid-19 focused in the European environment," *J. Hosp. Health Care Admin*. vol. 4, p. 149, 2021. doi: 10.29011/2688-6472.000149.

[2] N. Navaz, M. A. Serhani, H. T. El Kassabi, N. Al-Qirim, and H. Ismail, "Trends, technologies, and key challenges in smart and connected healthcare," *IEEE Access*, vol. 9, pp. 74044–74067, 2021. doi: 10.1109/ACCESS.2021.3079217.

[3] K. T. Shilpa, "Digital healthcare: current trends, challenges and future perspectives," In: *Proceedings of the Future Technologies Conference (FTC) 2021, Volume 2. FTC 2021. Lecture Notes in Networks and Systems*, K. Arai, Ed., vol. 359, Cham, Springer, 2022. doi: 10.1007/978-3-030-89880-9_48.

[4] Reinventing & Redefining Technology. https://www.manoramahealthcare.com/technologies.php.

[5] How the 'Healthcare-as-a-Service' concept works as a business and care model. 2021. https://www.businessinsider.com/sc/how-healthcare-as-a-service-can-improve-the-health-system 2021-5?IR=T.

[6] Emerging Technology Trends Shaping the Healthcare Industry. 2019. https://blog.relecura.com/2019/02/emerging-technology-trends-shaping-the-healthcare-industry/.

[7] G. Rouleau, M. P. Gagnon and J. Côté, "Impacts of information and communication technologies on nursing care: an overview of systematic reviews (protocol)," *Syst. Rev.*, vol. 4, p. 75, 2015. doi: 10.1186/s13643-015-0062-y.

[8] ICT in Health Care. http://pmssymohfw.nic.in/index1.php? lang = 1&level = 1&sublinkid = 23&lid = 50.

[9] 4 Ways Technology Is Improving Patient Safety. 2017. https://www.healthitoutcomes.com/doc/waystechnology-improving-patient-safety-0001.

[10] How to Improve Care Coordination With Technology. 2017. https://www.texturehealth.com/blog/how-toimprove-care-coordination-with-technology.

[11] How To Reduce Healthcare Cost Using Technology. 2021. https://www.tripleaimsoftware.com/how-toreduce-healthcare-cost-using-technology/.

[12] K. C. Tseng and C. C. Wu, "An expert fitness diagnosis system based on elastic cloud computing," *Sci. World J.*, vol. 2014, 2014.

[13] S. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, "The internet of things for health care: a comprehensive survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.

[14] G. Wolgast, C. Ehrenborg, A. Israelsson, J. Helander, E. Johansson, and H. Manefjord, "Wireless body area network for heart attack detection [education corner]," *IEEE Antennas Propag. Mag.*, vol. 58, no. 5, pp. 84–92, Oct. 2016.

[15] P. Gope and T. Hwang, "BSN-Care: A secure IoT-based modern healthcare system using body sensor network," *IEEE Sens. J.*, vol. 16, no. 5, pp. 1368–1376, 2016.

[16] Z. U. Ahmed, M. G. Mortuza, M. J. Uddin, M. H. Kabir, M. Mahiuddin, and M. J. Hoque, "Internet of things based patient health monitoring system using wearable biomedical device," In: *2018 International Conference on Innovation in Engineering and Technology (ICIET)*, IEEE, 2018, December, 1–5.

[17] J. Saha, A. K. Saha, A. Chatterjee, S. Agrawal, A. Saha, A. Kar, et al., "Advanced IOT based combined remote health monitoring, home automation and alarm system," *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, 2018. doi: 10.1109/ccwc.2018.8301659.

[18] Why Education Matters to Health: Exploring the Causes. 2015. https://societyhealth.vcu.edu/work/theprojects/why-education-matters-to-health-exploring-the-causes.html.

[19] Information Communication Technology in HealthCare. 2018. https://www.frontenders.in/blog/information-communication-technology-healthcare.html.

[20] https://www.forbes.com/sites/forbesbusinesscouncil/2021/11/18/digital-transformation-trends-inhealthcare-to-watch-in-2021/?sh=f6297e557ef5.

[21] Digital Transformation in Healthcare in 2021: 7 Key Trends. 2021. https://www.digitalauthority.me/resources/state-of-digital-transformation-healthcare/.

[22] Accessed On. https://www.osplabs.com/insights/the-who-what-why-and-how-of-healthcarecloud-strategy/.

[23] K. T. Shilpa, "Blockchain and cloud technology: Leading the ICT innovations," In: *ICT Systems and Sustainability. Lecture Notes in Networks and Systems*, M. Tuba, S. Akashe, A. Joshi, Eds., Singapore, Springer, 2022, vol. 321. doi: 10.1007/978-981-16-5987-4_41.

[24] L. M. Dang, M. J. Piran, D. Han, K. Min, and H. Moon, "A survey on internet of things and cloud computing for healthcare," *Electronics*, vol. 8, no. 7. p. 768, 2019. doi: 10.3390/electronics8070768.

[25] P. K. Bollineni and K. Neupane, "*Implications for adopting cloud computing in e-Health*," Lambert Academic Publishing, Saarbrücken, 2011.

[26] O. Ali, A. Shrestha, J. Soar, and S. F. Wamba, "Cloud computing-enabled healthcare opportunities, issues, and applications: A systematic review," *Int. J. Inf. Manag.*, vol. 43, pp. 146–158, 2018.

[27] https://theiotmagazine.com/iot-in-healthcare-how-it-improves-medical-software-4ca703ea1130.

[28] A. S. Abdulbaki, S. A. D. M. Najim, and S. A. Khadim, "Eczema disease detection and recognition in cloud computing," *Int. J. Appl. Eng. Res.*, vol. 12, no. 24, pp. 14396–14402, 2017.

[29] P. M. Kumar, S. Lokesh, R. Varatharajan, G. Chandra Babu, and P. Parthasarathy, "Cloud and IoT based disease prediction and diagnosis system for healthcare using Fuzzy neural classifier," *Future Gener. Comput. Syst.*, vol. 86, pp. 527–534, 2018.

[30] H. Xia, I. Asif and X. Zhao, "Cloud-ECG for real time ECG monitoring and analysis," *Comput. Methods Prog. Biomed.*, vol. 110, no. 3, pp. 253–259, 2013. doi: 10.1016/j.cmpb.2012.11.008.

[31] N. Sahanaa Sree and N. Banupriya, "A cloud based risk prediction of coronary heart disease," *Int. J. Appl. Eng.*, vol. 13, no. 5, pp. 2786–2790, 2018.

[32] N. Gupta, N. Ahuja, S. Malhotra, A. Bala, and G. Kaur, "Intelligent heart disease prediction in cloud environment through ensembling," *Expert. Syst.*, vol. 34, no. 3. p. e12207, 2017. doi: 10.1111/exsy.12207.

[33] V. Aswin and S. Deepak, "Medical diagnostics using cloud computing with fuzzy logic and uncertainty factors," *2012 International Symposium on Cloud and Services Computing*, Mangalore, India, 2012. doi: 10.1109/iscos.2012.29.

[34] V. Lahoura, H. Singh, A. Aggarwal, B. Sharma, M. A. Mohammed, R. Damaševičius, et al., "Cloud computing-based framework for breast cancer diagnosis using extreme learning machine," *Diagnostics*, vol. 11, p. 241, 2021. doi: 10.3390/diagnostics11020241.

[35] M. A. Khan, S. Abbas, A. Atta, A. Ditta, H. Alquhayz, M. F. Khan, et al., "Intelligent cloud based heart disease prediction system empowered with supervised machine learning," *Comput. Mater. Continua*, vol. 65, no. 1, pp. 139–151, 2020.

[36] F. Khan, M. A. Khan, S. Abbas, A. Athar, S. Y. Siddiqui, A. H. Khan, et al., "Cloud-based breast cancer prediction empowered with soft computing approaches," *J. Healthc. Eng.*, vol. 2020, pp. 1–16, 2020.

[37] https://www.digitalauthority.me/resources/big-data-in-healthcare/.

[38] https://www.optisolbusiness.com/insight/importance-of-big-data-in-healthcare.

[39] N. Zhu, T. Diethe, M. Camplani, L. Tao, A. Burrows, N. Twomey, et al., "Bridging e-health and the internet of things: The SPHERE project," *IEEE Intell. Syst.*, vol. 30, no. 4, pp. 39–46, 2015. doi: 10.1109/mis.2015.57.

[40] P. Verma and S. K. Sood, "Cloud-centric IoT based disease diagnosis healthcare framework," *J. Parallel Distrib. Comput.*, vol. 116, pp. 27–38, 2018. doi: 10.1016/j.jpdc.2017.11.018.

[41] I. Raeesi Vanani and M. Amirhosseini, "IoT-based diseases prediction and diagnosis system for healthcare," In: *Internet of Things for Healthcare Technologies. Studies in Big Data*, C. Chakraborty, A. Banerjee, M. Kolekar, L. Garg, B. Chakraborty, Eds., vol. 73, Singapore, Springer, 2021. doi: 10.1007/978-981-15-4112-4_2.

[42] R. Ani, S. Krishna, N. Anju, M. S. Aslam, and O. S. Deepa, "Iot based patient monitoring and diagnostic prediction tool using ensemble classifier," *2017 International Conference on Advances in Computing, Communication*, 2017.

[43] A. M. Ghosh, D. Halder, and S. K. A. Hossain, "Remote health monitoring system through IoT," *2016 5th International Conference on Informatics, Electronics and Vision (ICIEV)*, 2016. doi: 10.1109/iciev.2016.7760135.

[44] S. Kale, S. Mane, and P. Patil, "IOT based wearable biomedical monitoring system," *2017 International Conference on Trends in Electronics and Informatics (ICEI)*, 2017. doi: 10.1109/icoei.2017.8300852.

[45] P. Kaur, R. Kumar, and M. Kumar, "A healthcare monitoring system using random forest and internet of things (IoT)," *Multimed. Tools Appl.*, vol. 78, no. 14, pp. 19905–19916, 2019.

[46] L. K. Sahu, P. K. Vyas, V. Soni, and A. Deshpande, "Survey of recent studies on healthcare technologies and computational intelligence approaches and their applications," In: *Computational Intelligence and Applications for Pandemics and Healthcare*, IGI Global, 2022, pp. 282–307.

[47] https://data-flair.training/blogs/machine-learning-in-healthcare/.

[48] R. Venkatesh, C. Balasubramanian, and M. Kaliappan, "Development of big data predictive analytics model for disease prediction using machine learning technique," *J. Med. Syst.*, vol. 43, p. 272, 2019. doi: 10.1007/s10916-019-1398-y.

[49] R. G. Saboji, "A scalable solution for heart disease prediction using classification mining technique," *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, 2017. doi: 10.1109/icecds.2017.8389755.

[50] S. Mohan, C. Thirumalai, and G. Srivastava, "Effective heart disease prediction using hybrid machine learning techniques," *IEEE Access*, vol. 7, pp. 81542–81554, 2019.

[51] A. Corsi, F. F. de Souza, R. N. Pagani, and J. L. Kovaleski, "Big data analytics as a tool for fighting pandemics: a systematic review of literature," *J. Ambient. Intell. Humanized Comput.*, vol. 12, no. 10, pp. 1–18, 2020.

[52] C. Pasupathi and V. Kalavakonda, "Evidence Based health care system using Big Data for disease diagnosis," *2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, 2016. doi: 10.1109/aeeicb.2016.7538393.

[53] A. A. Mohammed, R. Basa, A. K. Kuchuru, S. P. Nandigama, and M. Gangolla, "Random forest machine learning technique to predict heart disease," *Eur. J. Mol. Clin. Med.*, vol. 7, no. 4. p. 2020, 2020.

[54] S. H. Koppad and A. Kumar, "Application of big data analytics in healthcare system to predict COPD," *2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT)*, 2016. doi: 10.1109/iccpct.2016.7530248.

[55] N. Das, L. Das, S. S. Rautaray, and M. Pandey, "Detection and prevention of hiv aids using big data tool," In: *2018 3rd International Conference for Convergence in Technology (I2CT)*, IEEE, 2018 April, 1–5.

[56] C. A. Alexander and L. Wang, "Big data analytics in heart attack prediction," *J. Nurs. Care*, vol. 6, no. 2, 2017. doi: 10.4172/2167-1168.1000393.

[57] A. Ismail, S. Abdlerazek, and I. M. El-Henawy, "Big data analytics in heart diseases prediction," *J. Theor. Appl. Inf. Technol.*, vol. 98, no. 11, pp. 15–19, 2020.

[58] P. Singh, A. Kaur, R. S. Batth, S. Kaur, and G. Gianini, "Multi-disease big data analysis using beetle swarm optimization and an adaptive neuro-fuzzy inference system," *Neural Comput. Appl.*, vol. 33, no. 16, pp. 1–12, 2021.

[59] https://www.practicebuilders.com/blog/4-ways-blockchain-is-revolutionizing-healthcare/.

[60] R. Ben Fekih and M. Lahami, "Application of blockchain technology in healthcare: A comprehensive study," *The Impact of Digital Technologies on Public Health in Developed and Developing Countries: 18th International Conference, ICOST 2020, Hammamet, Tunisia, June 24–26, 2020, Proceedings*, vol. 12157, 2020, pp. 268–276. doi: 10.1007/978-3-030-51517-1_23.

[61] R. El-Bialy, M. A. Salamay, O. H. Karam, and M. E. Khalifa, "Feature analysis of coronary artery heart disease data sets," *Procedia Comput. Sci.*, vol. 65, pp. 459–468, 2015. doi: 10.1016/j.procs.2015.09.132.

[62] S. Ghosh, *Application of various data mining techniques to classify heart diseases*, Doctoral dissertation, Dublin, National College of Ireland, 2017.

[63] J. Xia, H. Chen, Q. Li, M. Zhou, L. Chen, Z. Cai, et al., "Ultrasound-based differentiation of malignant and benign thyroid Nodules: An extreme learning machine approach," *Comput. Methods Prog. Biomed.*, vol. 147, pp. 37–49, 2017. doi: 10.1016/j.cmpb.2017.06.005.

[64] K. Sultan, I. Naseer, R. Majeed, D. Musleh, M. A. S. Gollapalli, S. Chabani, and M. A. Khan, "Supervised machine learning-based prediction of COVID-19," *Comput., Mater. Continua*, vol. 69, no. 1, pp. 21–34, 2021.

[65] D. Dahiwade, G. Patle, and E. Meshram, "Designing disease prediction model using machine learning approach," *2019 3rd International Conference on Computing Methodologies and Communication (ICCMC)*, Erode, India, 2019. doi: 10.1109/iccmc.2019.8819782.

[66] D. Shah, S. Patel, and S. K. Bharti, "Heart disease prediction using machine learning techniques," *SN Comput. Sci.*, vol. 1, no. 6, pp. 1–6, 2020.

[67] N. L. Fitriyani, M. Syafrudin, G. Alfian, and J. Rhee, "Development of disease prediction model based on ensemble learning approach for diabetes and hypertension," *IEEE Access*, vol. 7, pp. 144777–144789, 2019. doi: 10.1109/ACCESS.2019.2945129.

[68] H. D. Masethe and M. A. Masethe, "Prediction of heart disease using classification algorithms," In: *World Congress on Engineering and Computer Science 2014 Vol II WCECS 2014*, San Francisco, USA, 2014, 22–24 Oct.

[69] M. Chen, Y. Hao, K. Hwang, L. Wang, and L. Wang, "Disease prediction by machine learning over big data from healthcare communities," *IEEE Access*, vol. 5, pp. 8869–8879, 2017. doi: 10.1109/ACCESS.2017.2694446.

[70] S. Aftab, S. Alanazi, M. Ahmad, M. A. Khan, A. Fatima, and N. S. Elmitwally, "Cloud-based diabetes decision support system using machine learning fusion," *Comput. Mater. Continua*, vol. 68, no. 1, pp. 1341–1357, 2021.

[71] S. Secinaro, D. Calandra, A. Secinaro, V. Muthurangu, and P. Biancone, "The role of artificial intelligence in healthcare: a structured literature review," *BMC Med. Inf. Decis. Mak.*, vol. 21, p. 125, 2021. doi: 10.1186/s12911-021-01488-9.

[72] https://www.delveinsight.com/blog/robotics-in-healthcare.

[73] M. Butter, A. Rensma, S. Kalisingh, M. Schoone, M. Leis, G. J. Gelderblom, et al., *Robotics for healthcare*, European Commission EC, Netherlands Organization for Applied Scientific Research (TNO), 2008.

[74] https://royaljay.com/healthcare/neural-networks-inhealthcare/#:~:text = Neural%20networks%20can%20be%20seen%20in%20most%20places,profes sionals%20discover%20safer%20and%20more%20effective%20medicines%20fast.

[75] P. G. Shynu, V. G. Menon, R. L. Kumar, S. Kadry, and Y. Nam, "Blockchain-based secure healthcare application for diabetic-cardio disease prediction in fog computing," *IEEE Access*, vol. 9, pp. 45706–45720, 2021. doi: 10.1109/ACCESS.2021.3065440.

[76] T. Frikha, A. Chaari, F. Chaabane, O. Cheikhrouhou, and A. Zaguia, "Healthcare and fitness data management using the IoT-based blockchain platform," *J. Healthc. Eng.*, vol. 2021, p. 9978863, 12 pages, 2021. doi: 10.1155/2021/9978863.

[77] A. Azaria, A. Ekblaw, T. Vieira, and A. Lippman, MedRec: Using blockchain for medical data access and permission management, *2016 2nd International Conference on Open and Big Data (OBD)*, 2016. doi: 10.1109/obd.2016.11.

[78] G. Jain and A. Jain, Applications of AI, IoT, and robotics in healthcare service based on several aspects, In: *Blockchain technology in healthcare applications*, CRC Press, Florida, USA, 2022, pp. 87–114.

[79] N. Pavithra and D. N. Afza, "Issues and challenges in adopting robotics in healthcare-A conceptual study," *J. Posit. Sch. Psychol.*, vol. 6, no. 8, pp. 4266–4270, 2022.

[80] https://www.dailypioneer.com/2022/columnists/robotics-is-changing–healthcare.html#:~:text = Application%20of%20robotics%20in%20healthcare,patients%20with%20long-term%20conditions.

[81] A. Joseph, B. Christian, A. A. Abiodun, and F. Oyawale, "A review on humanoid robotics in healthcare," In: *MATEC Web of Conferences*, Vol. 153, EDP Sciences, 2018, p. 02004.

[82] https://www.dell.com/en-us/blog/healthcare-trends-in-neural-networks/.

[83] D. Lavanya and K. U. Rani, "Performance evaluation of decision tree classifiers on medical datasets," *Int. J. Comput. Appl.*, vol. 26, no. 4, pp. 1–4, 2011.

[84] R. Chowdhury, M. Chatterjee, and R. Samanta, "An artificial neural network model for neonatal disease diagnosis," *Int. J. Artif. Intell. Expert. Syst. (IJAE)*, vol. 2, no. 3, pp. 96–106, 2011.

[85] B. Zebardast, A. Ghaffari, and M. Masdari, "A new generalized regression artificial neural networks approach for diagnosing heart disease," *Int. J. Innov. Appl. Stud.*, vol. 4, no. 4, pp. 679–689, 2013.

[86] C. B. Sivaparthipan, B. A. Muthu, G. Manogaran, B. Maram, R. Sundarasekar, S. Krishnamoorthy, et al., "Innovative and efficient method of robotics for helping the Parkinson's disease patient using IoT in big data analytics," *Trans. Emerg. Telecommun. Technol.*, vol. 31, no. 12. p. e3838, 2020.

[87] J. Mohana, B. Yakkala, S. Vimalnath, P. M. Benson Mansingh, N. Yuvaraj, K. Srihari, et al., "Application of internet of things on the healthcare field using convolutional neural network processing," *J. Healthc. Eng.*, vol. 2022, p. 1892123, 2022.

[88] https://www.allerin.com/blog/top-5-applications-of-deep-learning-in-healthcare.

[89] S. Keesara, A. Jonas, and K. Schulman, "Covid-19 and health care's digital revolution," *N. Engl. J. Med.*, vol. 382, no. 23. p. e82, 2020. doi: 10.1056/nejmp2005835.

[90] S. Yang, P. Fichman, X. Zhu, M. Sanfilippo, S. Li, and K. R. Fleischmann, "The use of ICT during COVID-19," *Proc. Assoc. Inf. Sci. Technol.*, vol. 57, p. e297, 2020. doi: 10.1002/pra2.297.

[91] A. Kapoor, S. Guha, M. K. Das, K. C. Goswami, and R. Yadav, "Digital healthcare: The only solution for better healthcare during COVID-19 pandemic? *Indian. Heart J.*, vol. 72, no. 2, pp. 61–64, 2020.

[92] https://towardsdatascience.com/medical-diagnosis-with-a-convolutional-neural-networkab0b6b455a20.

[93] D. R. Sarvamangala and R. V. Kulkarni, "Convolutional neural networks in medical image understanding: a survey," *Evol. Intel.*, vol. 15, no. 4, pp. 1–22, 2021. doi: 10.1007/s12065-020-00540-3.

[94] S. S. Yadav and S. M. Jadhav, "Deep convolutional neural network based medical image classification for disease diagnosis," *J. Big Data*, vol. 6, p. 113, 2019. doi: 10.1186/s40537-019-0276-2.

[95] L. Wang and A. Wong, COVID-Net: A Tailored Deep Convolutional Neural Network Design for Detection of COVID-19 Cases from Chest Radiography Images, *arXiv preprint arXiv:2003.09871*, 2020.

[96] R. M. Sadek, S. A. Mohammed, A. R. K. Abunbehan, A. K. H. A. Ghattas, M. R. Badawi, M. N. Mortaja, et al., "Parkinson's disease prediction using artificial neural network" *Int. J. Acad. Health Med. Res.*, vol. 3, pp. 1–8, 2019. http://ijeais.org/wpcontent/uploads/2019/01/IJAHMR190101.

[97] Z. Soltani and A. Jafarian, "A new artificial neural networks approach for diagnosing diabetes disease type II," *Int. J. Adv. Comput. Sci. Appl.*, vol. 7, no. 6, pp. 89–94, 2016.

[98] N. S. El_Jerjawi and S. S. Abu-Naser, "Diabetes prediction using artificial neural network," *Int. J. Adv. Sci. Technol.*, vol. 121, pp. 55–64, 2018.

[99] Y. Zhang, Z. Lin, Y. Kang, R. Ning, and Y. Meng, "A feed-forward neural network model for the accurate prediction of diabetes mellitus," *Int. J. Sci. Technol. Res.*, vol. 7, no. 8, pp. 151–155, 2018, https://www.scopus.com/inward/record.uri? eid = 2-s2.085059910862&partnerID = 40&md5 = 40cdc4d37e47645feb76229e7b9c9dfd.

[100] M. Asad, U. Qamar, and M. Abbas, "Blood glucose level prediction of diabetic type 1 patients using nonlinear autoregressive neural networks," *J. Healthc. Eng.*, vol. 2021, p. 6611091, 7 pages, 2021. doi: 10.1155/2021/6611091.

[101] S. Tuli, N. Basumatary, S. S. Gill, M. Kahani, R. C. Arya, G. S. Wander, et al., "Healthfog: An ensemble deep learning based smart healthcare system for automatic diagnosis of heart diseases in integrated iot and fog computing environments," *Future Gener. Comput. Syst.*, vol. 104, pp. 187–200, 2020.

[102] F. Ali, S. El-Sappagh, S. M. R. Islam, D. Kwak, A. Ali, M. Imran, et al., "A smart healthcare monitoring system for heart disease prediction based on ensemble deep learning and feature fusion," *Inf. Fusion.*, vol. 63, pp. 208–222, 2020. doi: 10.1016/j.inffus.2020.06.008.

[103] S. N. Pasha, D. Ramesh, S. Mohmmad, and A. Harshavardhan, Cardiovascular disease prediction using deep learning techniques, In: *IOP Conference Series: Materials Science and Engineering*, Vol. 981. No. 2. IOP Publishing, 2020, December, p. 022006.

[104] H. Naz and S. Ahuja, "Deep learning approach for diabetes prediction using PIMA Indian dataset," *J. Diabetes Metab. Disord.*, vol. 19, no. 1, pp. 391–403, 2020.

[105] S. Shafqat, M. Fayyaz, H. A. Khattak, M. Bilal, S. Khan, O. Ishtiaq, et al., "Leveraging deep learning for designing healthcare analytics heuristic for diagnostics," *Neural Process. Lett.*, vol. 55, no. 1, pp. 53–79, 2021. doi: 10.1007/s11063021-10425-w.

[106] P. Silva, E. Luz, G. Silva, G. Moreira, R. Silva, D. Lucio, et al., "COVID-19 detection in CT images with deep learning: A voting-based scheme and cross-datasets analysis," *Inform. Med. Unlocked*, vol. 20, no. 1, p. 100427, 2020. doi: 10.1016/j.imu.2020.100427.

[107] E. E. D. Hemdan, M. A. Shouman, and M. E. Karar, COVIDX-Net: a framework of deep learning classifiers to diagnose Covid-19 in x-ray images, *arXiv preprint arXiv:2003.11055*, 2020.

[108] A. Bhandary, G. A. Prabhu, V. Rajinikanth, K. P. Thanaraj, S. C. Satapathy, D. E. Robbins, et al., "Deep-learning framework to detect lung abnormality – A study with chest X-Ray and lung CT scan images," *Pattern Recognit. Lett.*, vol. 129, pp. 271–278, 2019. doi: 10.1016/j.patrec.2019.11.013.