

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/354614019>

Blockchain technology applications in healthcare: An overview

Article in *International Journal of Intelligent Networks* · September 2021

DOI: 10.1016/j.ijin.2021.09.005

CITATIONS

141

READS

1,515

5 authors, including:



Abid Haleem

Jamia Millia Islamia

546 PUBLICATIONS 19,907 CITATIONS

[SEE PROFILE](#)



Mohd Javaid

Jamia Millia Islamia

248 PUBLICATIONS 13,704 CITATIONS

[SEE PROFILE](#)



Ravi Pratap Singh

National Institute of Technology, Kurukshetra

166 PUBLICATIONS 4,914 CITATIONS

[SEE PROFILE](#)

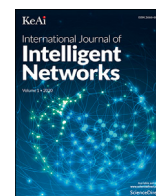


Rajiv Suman

G. B. Pant University of Agriculture and Technology, Pantnagar

98 PUBLICATIONS 4,972 CITATIONS

[SEE PROFILE](#)



Blockchain technology applications in healthcare: An overview

Abid Haleem^a, Mohd Javaid^{a,*}, Ravi Pratap Singh^b, Rajiv Suman^c, Shanay Rab^d

^a Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India

^b Department of Industrial and Production Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar, Punjab, India

^c Department of Industrial & Production Engineering, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

^d Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, 110025, India



ARTICLE INFO

Keywords:

Blockchain
Healthcare
Data storage
Clinical trials
Capabilities
Technology

ABSTRACT

Blockchain is an emerging technology being applied for creating innovative solutions in various sectors, including healthcare. A Blockchain network is used in the healthcare system to preserve and exchange patient data through hospitals, diagnostic laboratories, pharmacy firms, and physicians. Blockchain applications can accurately identify severe mistakes and even dangerous ones in the medical field. Thus, it can improve the performance, security, and transparency of sharing medical data in the health care system. This technology is helpful to medical institutions to gain insight and enhance the analysis of medical records. In this paper, we studied Blockchain technology and its significant benefits in healthcare. Various Capabilities, Enablers, and Unified Work-Flow Process of Blockchain Technology to support healthcare globally are discussed diagrammatically. Finally, the paper identifies and debates fourteen significant applications of Blockchain for healthcare. Blockchain plays a decisive part in handling deception in clinical trials; here, the potential of this technology offer is to improve data efficiency for healthcare. It can help avoid the fear of data manipulation in healthcare and supports a unique data storage pattern at the highest level of security. It provides versatility, interconnection, accountability, and authentication for data access. For different purposes, health records must be kept safe and confidential. Blockchain helps for the decentralised protection of data in healthcare and avoids specific threats.

1. Introduction

Blockchain is a decentralised and public digital ledger that records transactions on many computers so that no record involved can be altered retroactively without altering any blocks afterwards. Blockchain is verified and linked to the preceding 'block,' forming a long chain. After all, Blockchain is the name of the record. As any transaction is registered and checked publicly, Blockchain provides a good deal of accountability. When entered, no one can modify all the information written in the Blockchain. It serves to demonstrate that the data is actual and unchanged. In Blockchain, data are maintained on networks instead of a central database, improving stability and showing its proneness to be hacked. Blockchain offers a fantastic forum to develop and compete with traditional companies for modern and creative business models [1–3].

Blockchain helps marketers to maintain an overview of the products used in medicine. Health and pharmaceuticals will get rid of counterfeit medications using Blockchain technologies, enabling tracing of all these medicines. It helps discover the cause of falsification. Blockchain can

guarantee the confidentiality of patient records; when medical history is developed, Blockchain can also store it, and this record cannot be modified. This decentralised network is used with all commodity hardware in the hospital. Researchers allow computing estimates for therapies, medicines, and remedies of diverse illnesses and disorders using the resources saved by these devices [4,5].

Blockchain is a distributed ledger network that adds and never deletes or modifies records without a common consensus. A Blockchain hash's value depends on a cryptographic hash that connects newly added information block records with each data block. The distributed Blockchain ledger architecture ensures that data is not processed in any centralised venue, making it accessible and accountable to all network users. This decentralised system avoids a single attack, strengthening and securing the system. It facilitates better control of health records and patient care by minimising twice the amount of medical practice and monitoring, saving both practitioners and patients time and resources. The patient will watch where their information goes and achieve it by keeping health records on a blockchain [6,7].

* Corresponding author.

E-mail addresses: ahaleem@jmi.ac.in (A. Haleem), mjavaid@jmi.ac.in (M. Javaid), singhrp@nitj.ac.in (R.P. Singh), raje.suman@gmail.com (R. Suman), shanayrab753@gmail.com (S. Rab).

<https://doi.org/10.1016/j.ijin.2021.09.005>

Received 16 May 2021; Received in revised form 12 September 2021; Accepted 13 September 2021

Available online 15 September 2021

2666-6030/© 2021 The Author(s). Published by Elsevier B.V. on behalf of KeAi Communications Co., Ltd. This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0/>).

Scholars can use this technology to analyse a massive volume of unveiled knowledge about a particular group of individuals. It helps for the advancement of precision medicine to be provided appropriately for longitudinal research. We use Blockchain for healthcare in real-time with the help of the Internet of Things (IoT) and wearable's devices to store and update valuable patient data such as blood pressure and sugar level. It helps doctors track patients who are vulnerable to high risk and, if an emergency occurs, advise and alert their careers and families. Blockchain has a decentralised structure that allows it safely to hack and avoids compromising any single copy of the records [8,9]. This article addresses the following research questions:

- RQ1:** To study Blockchain technology and its significant needs in healthcare;
- RQ2:** to identify capabilities of Blockchain technology to support the healthcare culture globally;
- RQ3:** to identify and discuss enablers of Blockchain technology for reviving healthcare services;
- RQ4:** to identify the 'Unified Work-Flow Process' of Blockchain technology realization in providing healthcare amenities;
- RQ5:** to identify and discuss significant applications of Blockchain for healthcare.

1.1. Blockchain

Blockchain is a decentralised node network that stores the data. It is an excellent technology for protecting confidential data within the system. This technology helps to exchange critical data and keeps it secure and confidential. It is a perfect tool to hold all the related documents in one location and securely. Blockchain also speeds up searches for applicants that fulfil specific trial criteria using a single patient database. The Blockchain can be described as a decentralised peer-to-peer (P2P) network of personal computers called nodes, which maintains, stores, and records historical or transaction data [10–12]. It allows a reliable collaboration as the information is stored and exchanged by all network members and keeps a constant track of past and current experiences. This technology can integrate disparate networks to provide insights into the importance of individual treatment. Thus, Blockchain can well be recognised for immutability and safety. Blocks, nodes, and miners are the three main ideas in Blockchain. Blockchain does not save any of its data in a single location. Instead, a network of computers copies and spreads the Blockchain. Every computer on the web updates its Blockchain to reflect a new block to the Blockchain. Fig. 1 shows the basic working steps of Blockchain technology.

A Blockchain system runs on top of the internet, on a P2P network of computers that all run the protocol and have an identical copy of the transaction ledger, allowing for P2P value transactions without using an

intermediary by machine consensus. There are various types of Blockchain technologies such as public, private, hybrid, or consortium. Each Blockchain network has different advantages and disadvantages that essentially influence its optimal applications.

- The public Blockchain is the first type of Blockchain technology, and it is where Bitcoin and other cryptocurrencies were conceived and helped promote distributed ledger technology (DLT). It eliminates the drawbacks of centralisation, such as a lack of security and transparency. DLT distributes data throughout a P2P network rather than storing it in a single location. Because of its decentralised nature, it necessitates some method of data authentication.
- A private Blockchain is a Blockchain network that operates in a restricted context, such as a closed network, or is controlled by a single entity. While it functions similarly to a public blockchain network regarding P2P connectivity and decentralisation, it is substantially smaller. In a private Blockchain, the network's inventor knows who the participants are from the start. One cannot develop a permission-based solution on a public web, and users have complete anonymity.
- Organisations who desire the best of both worlds will sometimes employ hybrid Blockchain, a type of Blockchain that includes private and public Blockchain characteristics. It allows businesses to create a private, permission-based system alongside a public, permissionless system, letting them regulate who has access to specific data stored on the Blockchain and what data is made public.

1.2. Need of blockchain in healthcare

As far as healthcare is concerned, the urgency of development increases to more incredible speeds. Today the need is for quality health facilities supported by advanced and newer technologies. Here, Blockchain would play a critical role in transforming the healthcare sector. In addition, the landscape of the health system is moving towards a patient-centred approach focusing on two main aspects: accessible services and appropriate healthcare resources at all times. The Blockchain enhances healthcare organisations to provide adequate patient care and high-quality health facilities. Health Information Exchange is another time-consuming and repetitive process that leads to high health industry costs, quickly sorted out using this technology. Using Blockchain technology, citizens may take part in health study programs. In addition, better research and shared data on public wellbeing will enhance treatment for different communities. A centralised database is used to manage the entire healthcare system and organisations [13–15].

Until now, the most significant problems faced are data protection, sharing, and interoperability in population health management. This particular problem is reliable by using Blockchain. This technology enhances security, data exchange, interoperability, integrity, and real-time

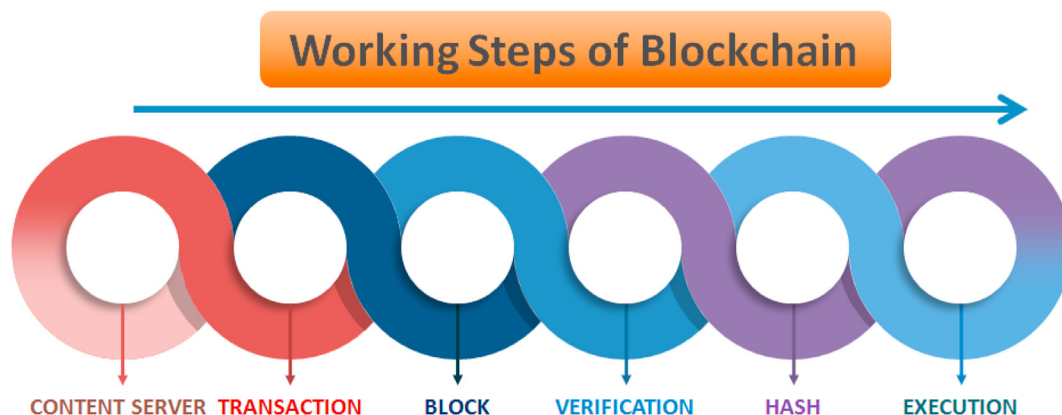


Fig. 1. Working steps of Blockchain Technology.

updating and access when correctly implemented. There are also significant concerns about data protection, especially in the fields of personalised medicine and wearables. Patients and medical personnel require safe and straightforward means of recording, sending, and consulting data over networks without safety concerns; thus, Blockchain technology is implemented to resolve these issues [16,17].

2. Various Capabilities of Blockchain Technology to support the healthcare culture globally

In healthcare, Blockchain has a wide range of applications and functions. The ledger technology helps healthcare researchers uncover genetic code by facilitating the secure transfer of patient medical records, managing the drug supply chain, and facilitating the safe transfer of patient medical records. Fig. 2 reflects the variety of features and critical enablers of Blockchain philosophy in umpteen healthcare spheres and its allied domains. Protection of healthcare data, various genomics management, electronic data management, medical records, interoperability, digitalised tracking and issues outbreak, etc., are some of the technically derived and impressive features employed to develop and practice Blockchain technology. The complete digitalised aspects of Blockchain technology and its use in healthcare-related applications are the significant reasons for its adoption [18,19].

The Blockchain makes the entire prescription process transparent, from manufacturing to pharmacy shelves. Congestion, freight direction, and speed may all be tracked using IoT and Blockchain. It offers the chance to schedule acquisitions efficiently to prevent disruptions and shortages in clinics, pharmacies, and other medical facilities with a given medication. The deployment of digital frameworks built on Blockchain would help ensure that the logistics data avoid uncontrolled adjustments. It increases trust and prevents the illicit handling of records, payments, and medication themselves by various people interested in purchasing drugs. The technology can effectively improve the condition of patients while at a competitive cost retaining the funds. It eliminates all obstacles and barriers in multi-level authentication [20–22]. Because Blockchain can preserve an incorruptible, decentralised, and transparent log of all patient data, it is ripe for security applications. Furthermore, while Blockchain is visible, it is also private, hiding any individual's identity behind complicated and secure algorithms that can preserve the sensitivity of medical data. Thanks to the technology's decentralised structure, patients, doctors, and healthcare providers can all share the same information swiftly and safely.

Blockchain technology makes the transition to interoperability led by patients easier as it allows patients to make their medical data accessible and access laws. This gives a patient greater power over personal information and improves confidentiality and privacy. The measurement and implementation of quality management and enforcement are difficult.

Any of these technical issues could be solved by Blockchain applications throughout the industry. Blockchain headlines will assist regulatory authorities in tracing legal drugs against falsified ones. This ensures that all approved parties exchange digital transactions containing the patient's details. Patients who move medical practitioners may merely update a single consent to exchange their complete records [23,24].

Blockchain has reached the healthcare industry with a rising acceptance rate. Also, in the early stages, people in the health ecosystem accept the technologies favourably. In the coming years, the holistic vision of Blockchain to transform the healthcare market will be to address problems affecting the present structure. It allows physicians, patients, and pharmacists to conveniently access all the available information at a given moment. Medical firms are exploring, experimenting, discovering day and night for Blockchain technologies, in the medical field for health records. It has confirmed itself as an irreplaceable instrument in healthcare by following pharmaceuticals, improving payment options, and decentralising patient health history records. In addition to robust technology such as machine learning & artificial intelligence, the medical sector is highly dependent on Blockchain. There are some genuine uses of how Blockchain changes the healthcare industry. The program is built on Blockchain monitoring technology to fine-tune the medical supply chain [25–27].

Blockchain's ability makes for a sophisticated data storage framework that records a person's whole health history of diagnosis, test reports, prior regimes, and even measurements by intelligent sensors. A doctor can conveniently obtain all the details available to make correct diagnoses and recommendations using this method. Because all the data in a single Blockchain system is stored, it is safe from loss and shift. To avoid an organisation's internal networks, it can use Blockchain. A significant organisation of many separate players, with various control levels on an encrypted Blockchain database, can save organisations from external risks and assaults. If a healthcare organisation correctly implements a Blockchain network, this will eliminate such rescue attacks and other problems, such as computer corruption or hardware failure [28,29].

3. Enablers of Blockchain Technology for reviving healthcare services

Fig. 3 illustrates the several on-ground industrial representatives of Blockchain capabilities to successfully implement healthcare culture perspectives and overall development. There have been various associated industrial/medical-care supporters or providers, which helps carry out the research and investigations for realising the Blockchain practices in healthcare and its core domains, too [30,31]. These observed providers BurstIQ, Guardtime, Robomed, Simply vital, Encrypgen, Chronicle, Tieion, etc., are the few agencies supplying and favouring the practising of Blockchain technology at ground levels.



Fig. 2. Capacities of blockchain technology for healthcare domain.

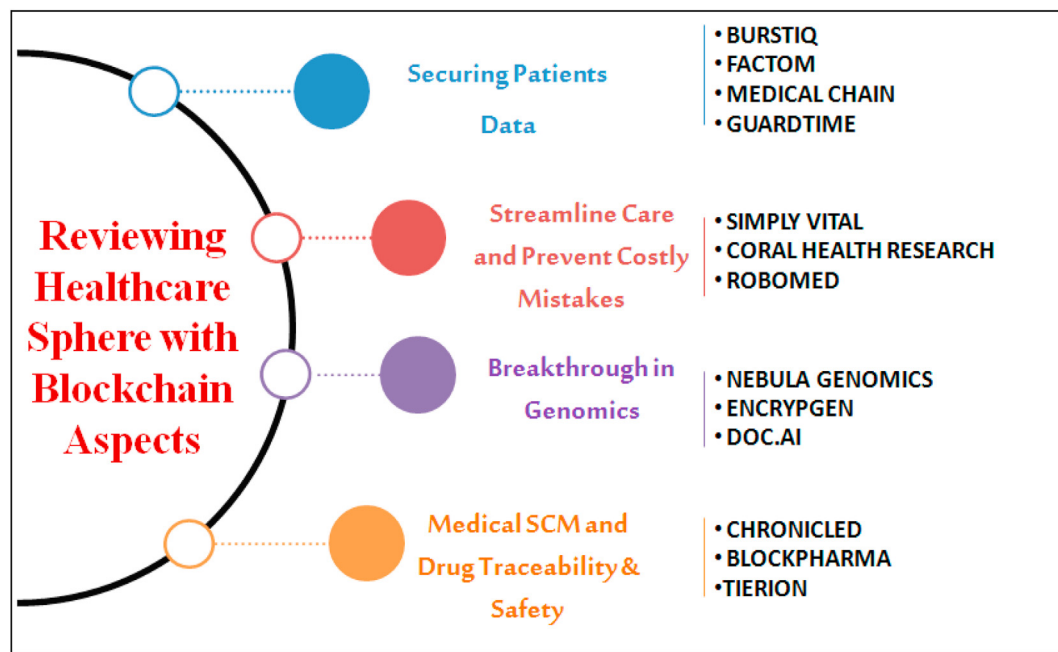


Fig. 3. Enablers of blockchain implementation in healthcare services.

Blockchain involves the development of new patient data cards for medical practitioners in other hospitals. Newly added information is usually repetitive and leads to loss of time, which is a severe health malfunction. Each individual can have different privileges or accessibility choices due to the location on the supply chain. In addition, any block containing the medication information would have a hash connected to it to another block.

Furthermore, the data transparency feature in the Blockchain framework will help find the entire root route and eradicate the distribution of fabricated drugs. A new medical card is established for the patient and deposited in a specific facility when the patient visits a new clinic. These details are ordinarily incomplete to the general public and contain collected records from the caregivers at the facilities concerned. Blockchain can conveniently assemble problems in the data processing. This technology will create open and similar Blockchain medical records around the world [32–34].

In healthcare, clinical trials are being conducted to assess the effectiveness of such therapies to treat or provide a partial remedy to a particular disease. Scientists can record data on test outcomes, person numbers, patient records, and other variables. Data collected during clinical trials should be authenticated so that scientists, pharmaceutical firms, and policymakers can be confident in the quality of results. In clinical trials, Blockchain technology could provide greater transparency and accountability. The health care Blockchain has enormous record-keeping leverage, as the blocks are made available to clinicians and patients, while the processing of medical history is done with an awareness of patient issues. Blockchain in the supply chain is very popular, and it also fits well for medicines in the healthcare area [35,36].

Blockchain provides easy forward-thinking on the practices and services of health professionals. In the health care industry, this Blockchain power operates to handle approval efficiently to process and acquire. It is convenient to avoid wastage by standing in a line to improve productivity and spruce up workflow with Blockchain. This technology aims to encourage personalised medicine, clinical advice, and practical research into health. Blockchain has become one of today's most popular technologies. The newest thing about the Blockchain is that the company believes that the platform can turn the healthcare industry more effectively. This will, in many ways, turn the healthcare industry into a reliable and stable digital directory. Blockchain healthcare technologies will

strengthen various challenges, such as clinical studies, patient records management, and prescription traceability [37,38].

Blockchains can be used successfully in healthcare to make the right choices in the health ecosystem. The distributed Blockchain platform offers the health sector opportunities to trace fraud, reduce overhead costs, reliably manufacture jobs, eliminate duplication of labour, enforce openness in the health environment. Further, it is used to hold assets, such as immutability and confidence, and decentralisation. The clinical trials and the approval organisations for the subject are the areas where Blockchain has the opportunity to boost medical professionals' and researchers' reliability, auditability, and accountability. The benefit for patients is that their medical histories are protected more confidently and that their diagnostic accuracy improves chances of further care [39,40].

In the processing of their health records, patients will now have a better voice. It will be allowed to exchange data as partners of the Blockchain network, thereby ensuring further privacy and control. Blockchain's pledge has widespread consequences for health care stakeholders. Disparate networks are likely to interact to provide insights and help evaluate treatment's importance based on this technology. An electronic medical records Blockchain network around the country will increase efficiencies and promote improved patient health results in the long run. In particular, Blockchain is a mutual, unchanging record of transactions made from connected transaction blocks and held in a digital booklet [41,42]. Medical details like patient life, medical equipment logs, or medical products' temperatures can be recorded during the shipping, following the medical field.

4. Unified Work-Flow Process of Blockchain Technology realization in healthcare amenities

Fig. 4 explores the schematic reflection about the integrated workflow for the overall development of Blockchain technology and its associated benefits/merits from a healthcare services perspective. The master patient indices claim adjustments, devoted medical supply chain management, interoperability, single and longitudinal records capturing, etc., are related benefits associated with the Blockchain practices in healthcare sectors [43,44]. The interactive work-process flow started with the distributed network flow, digitalised transactions, and shared data and ledger, which ultimately enables the Blockchain drivers to work

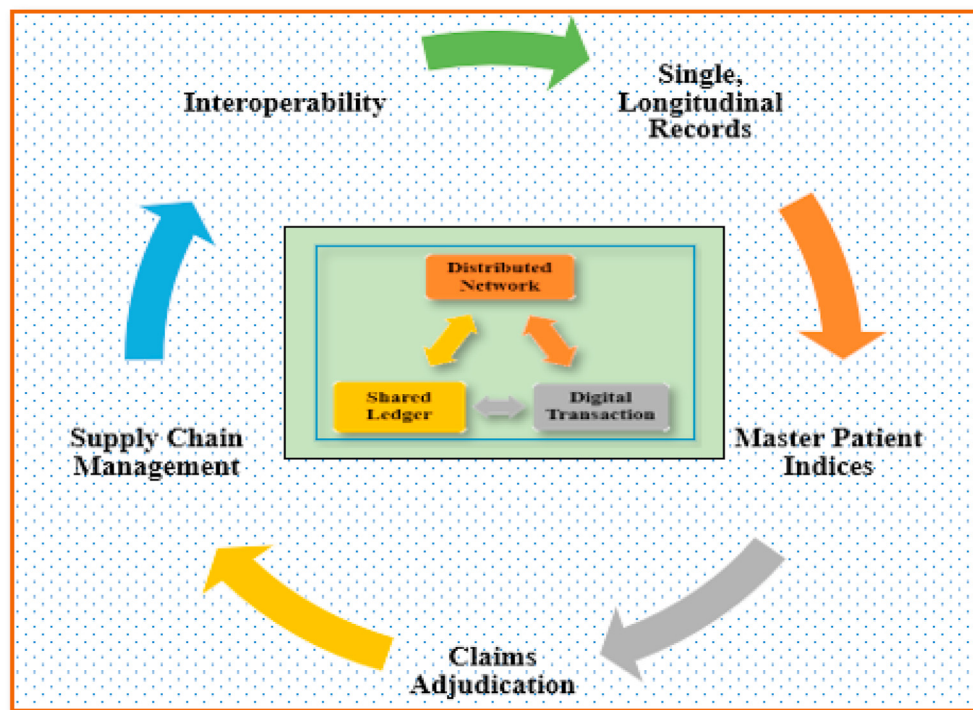


Fig. 4. Integrated work-flow process of blockchain technology for healthcare culture.

more emphasised to make healthcare services healthier and more innovative than before [43,45].

The principle of Blockchain technology is very straightforward and constantly evolving, increasing the network of blocks that adapt to the industries various needs and specific characteristics. The independent Blockchain framework provides a highly complete monitoring alternative and allows for the immediate refreshment of results. Blockchain will significantly minimise financial failures and also avoid theft and the illicit transferring of records. It can solve problems of changing results and snooping data. It allows the transfer of permanent time-stamped clinical trial reports and results, thus reducing scam and mistake occurrences in clinical trials. The health industry is primarily responsible for adopting Blockchain technologies [46–48].

Blockchain is a technology that in some way affects each industry. Particularly in areas where must create trust between different parties and stakeholders, Blockchain technologies are used. In the present fragmentation that a patient sees signing a new consent on any appointment, clinical operation, or medical test, Blockchain could radically alter the way informed consent has been granted. The exchange of clinical test data and the possibility of discovering benefits for testing subjects are some of Blockchain's commitments for these applications. Blockchain can become a fundamental aspect of the administration of consents to healthcare that facilitates knowledge exchange. Patients can now link to other hospitals and automatically receive their medical information via Blockchain technology [49–51].

An approved Blockchain is a closed network with connections to the networks for all system members. Thus, it is developed and used within organisations and companies to share information and render transfers safely. Once a transaction has been processed by consensus, it is considered a permanent record and added to the current Blockchain as a new block. The internet encourages everyone to build their website. Everyone in the network can communicate with other users in the same network in a Blockchain with no authorisation by generating their network address [52,53].

A Blockchain-driven supply chain system protects the protection, validity, and timeliness of the supply of medicinal products. It lets the producer maintain the right formulation blend according to medical

requirements. Medical devices can charge patient data, verify the treatment with the intended patient, and exchange procedural data anonymously with the patients and the regulators. Blockchain technologies are fascinating for the healthcare sector. In recent times, medical science with high-quality medical solutions has shown commendable progress. It is a distributed, transparent digital leader, used widely in many computers to monitor transactions. It is recognised for its significant effect on several markets and industries. This technology's existence addresses issues that existing approaches cannot resolve. Excellent healthcare needs confidence, protection, confidentiality, and data interoperability across different systems. Blockchain offers the chance to tackle it in new ways in healthcare [54–56].

Due to its eternal, autonomous, and completely open character, Blockchain shines out as a possible answer to health data protection. Using Blockchain, people's identity and medical records will remain privately held while the system remains stable. This revolutionary technology will facilitate the complex billing process by preventing ineffective and background instruments. In addition, it can help patients upload and enable approving parties to view medical records. By making electronic medical records more productive, reliable, and safe, Blockchain technology could provide a new paradigm of sharing health information. Blockchain is a ledger recording distributed and vital records of transactions [57–59].

5. Blockchain applications for healthcare

Blockchain is a relatively modern and emerging technology that has innovative applications during its successful healthcare implementation. Smooth, efficient data sharing and delivery across all the prominent network members and healthcare providers contribute to developing economical therapies and sophisticated treatments for many diseases. This will accelerate growth in healthcare in the coming years. The opportunities offered by Blockchain technology in the logistics industry have been revealed recently and show the healthcare sector's advantages. As this area directly affects life quality, it is one of the first areas in which digital transformation improves and innovations. At the same time, Blockchain technology is becoming more common, mainly in the

financial sphere. It offers several important and impressive chances for the healthcare industry, from science and logistics to relationships among practitioners and patients [60–62]. Table 1 discusses the significant applications of Blockchain for healthcare.

Blockchain's function is to document all sorts of transactions in a decentralised record, aside from other healthcare management structures. It is accurate and straightforward, saving time, effort, and cost efficiently and therefore saves on management effort. The biggest problem faced by the healthcare industry is the leaking of essential data and used for malicious devices and other special interests, which the applications of this technology can quickly sort out. Another area of importance is allowing users and parties to the database access to the latest up-to-date and authentic patient records and evaluations [124,125]. Blockchain's scope of health care looks super up-and-coming and exciting because it contributes to solving some of the industry's pressing issues. With Blockchain, we can connect therapy associates and other services to the network such that everybody has access to the same data. Many methods will bring positive benefits for businesses as a whole by using Blockchain technologies in health care. It provides patient information, medical science, clinical trials, the medical supply chain, and the integrity of medicinal products [126–128].

6. Discussion

Blockchain technology brings credibility and findings to clinical trials. Those records can be stored in the digital thumbprint as intelligent contracts on the Blockchain. Network infrastructure security at all levels, identity verification and authentication of all participants, and uniform patterns of authorisation to access electronic health information are only a few of the benefits of Blockchain Technologies in Healthcare. A Blockchain is used to maintain the monitoring of the pharmaceutical supply chain and tracking of medication responsibilities. This technology is applicable for storing the information of even an individual patient and, therefore, helps analyse and validate the effects of a particular procedure. Blockchain is used for health record-keeping, clinical trial, patient monitoring, improves safety, display information and transparency. It maintains the financial statements in hospitals and minimises the data transformation time and cost.

In the data-centred environment, it addresses several problems. Blockchain technology will generate a hash for individual blocks of patient health records. Blockchain system would also encourage patients to show their required data to third parties while keeping their identity confidential. A large quantity of data sets is needed to perform a clinical trial. The researchers concentrate on these data sets and perform routine experiments to provide analyses, estimates, and efficiency ratios under various circumstances. The data are analysed, and more decisions are made based on these findings. However, many scientists can manipulate the data and evidence gathered to alter the result.

Further, many drug makers want to record the findings that will provide their businesses with such advantages. Thus, researchers use Blockchain technology to make clinical studies fairer and more straightforward. It will help record clinical trials that are secure, uneven, and straightforward. The gathered knowledge can improve patient treatment and provide post-market analysis to optimise efficiency benefits. These standards are rooted in critical aspects of Blockchain technology such as open management, transparent auditing tracks, data transparency, robustness, and improved privacy and security. This allows healthcare providers to meet the current healthcare standards, including pharmaceutical supply safety.

7. Limitations and future scope

Blockchain technology is incorporated into the healthcare industry, in which specific challenges would have to be addressed. The big problem with the utilisation of this advanced technology for medical facilities is the lack of expertise. Blockchain applications are still in the early stages

Table 1

Significant applications Blockchain for healthcare.

S.No	Applications	Description	References
1	Store information of an individual patient	Before and after the different clinical study phases, a significant amount of patient information and health data is generated. There are many people's blood tests, quality assessments, estimates, and wellness polls. It can provide results that show the existence of some document or record. Healthcare providers traverse the stored data and suspect its validity, and they will check this seamlessly by matching it to the original records stored on the Blockchain system. Blockchain is based on existing cryptographic techniques, which include the appropriate framework for cryptography for data sharing. The patient's name, date of birth and diagnosis, treatments, and ambulatory history are recorded in EHR format during patient details by the healthcare provider. This information is stored in cloud computing or the current databases.	[63–66]
2	Analyse the effects of a particular procedure	Researchers can effectively analyse any particular procedure on a large part of the patient population through verified access to the patient data. This produces significant results that enhance the mode of management of these patient groups. With the Blockchain infrastructure in place, pharmaceutical firms will gather data in real-time to deliver a wide range of precisely adapted prescription drugs or services for patients. Blockchain makes the job of the pharmacies simpler since it has all the data on top of it. They will efficiently instruct patients on how to take the medication from these results. It will update the clinicians on the present stage of the patient with the wearable data gathered in real-time and alert them to any emergency.	[67–70]
3	Validation	Transactions are validated in a Blockchain until they are linked to the chain and are done by algorithms. The authenticity is sealed until the material is encrypted, digitally signed and saved. Healthcare companies, technological innovators, and the healthcare industry are trying to find opportunities to find out what it can do now and what it can do to make healthcare safer and cheaper in the future. Blockchain can make a breakthrough in the health ecosystem when healthcare management can adequately validate the results.	[71–75]
4	Safety and transparency	It provides excellent safety and transparency while enabling physicians to devote more time to treat patients. It would also allow supporting clinical trials and treatments for any rare disorder. Smooth data exchange among providers of medical solutions can	[76–79]

(continued on next page)

Table 1 (continued)

S.No	Applications	Description	References
		contribute to diagnostic precision, efficient therapies and cost-effective ecosystems in a healthcare system. Blockchain enables various health ecosystem organisations to remain in touch and exchange information on a commonly distributed leader for better safety and transparency. The users can exchange and monitor their data and other actions in the system without searching for more solutions for integrity and confidentiality when using such a system.	
5	Health record keeping	Blockchain can be a perfect technology for record-keeping in the medical world. Its applications include sharing healthcare data, keeping electronic healthcare records, managing insurance, and performing administrative tasks. Patients can send their health information via an app to a Blockchain network. The collaboration of sensors and intelligent devices is facilitated based on digital Blockchain contracts. In most cases, electronic health records are spread through various care institutions. Blockchain will unify all details and provide patients with historical access. The connection of all data in the same place will give us new perspectives on a patient's health status. Therefore, the Blockchain paradigm would ensure the information is authentic and legitimate and preserve users' privacy.	[80–84]
6	Clinical Trial	In clinical trials, Blockchain Technology is used to address problems of false results and data disintegration that do not match the purposes and objectives of the research. Blockchain will strengthen trust in clinical trials. The business analysis platform investigates the evolving market dynamics so that the healthcare sector understands the possibilities. The management of medicines on the Blockchain is just another chance of building and monitoring the chain from the manufacturer to the customer by incorporating Blockchain credibility.	[85–88]
7	Display information	The Blockchain system will display information about the origins of the medication to ensure high quality and that the approved medicine's manufacturer supplies it. Blockchain provides better protection than ever for sensitive data, provided that it is appropriately used. Various sectors, including finance, retail, and immobilisation, have begun to use the Blockchain app trend and achieve several benefits to display information. Healthcare is also considered to be nuanced and complicated. This declaration will lead to significant disputes. By its complexity and complexity, the	[89–92]

Table 1 (continued)

S.No	Applications	Description	References
		market has undergone fundamental developments in some fields, such as medicinal products, medications, vaccines, clinical trials, and cloud computing adoption.	
8	Identification of false content	Blockchain will provide more clarity and identification of false content. Clinical studies for participants and clients should still be easy to validate. An intelligent agreement is ideal for obtaining approval and keeping implemented protocol documents and their findings openly and publicly verifiable. The technology has first allowed the general public to monitor what occurs in a clinical trial closely. The motive behind this technology is that it is user-focused and offers safe access to health and insurance records to patients in real-time.	[93–97]
9	Reduces needless overhead expenses	Blockchain reduces needless overhead expenses and thus enables the correct use of health records. This technology will also mitigate the need for multiple intermediaries to monitor critical health information sharing. The crucial task of healthcare providers is to provide efficient, timely, and adequate services for their people may therefore be simplified. With Blockchain healthcare technologies, the service providers will already have an overview of the medical record of any particular patient. Many problems that plague the healthcare system can be resolved, including interoperability, report completion, theft and even catastrophe data failure.	[98–101]
10	Patient monitoring	A Blockchain's trust allows medical professionals to ensure they have access to medical equipment when necessary. Doctors may also be more time-consuming to watch patients and react distantly to health-related incidents. Via Blockchain and healthcare, monitoring temperatures inside patient rooms, beds use, and supply availability are improvable. A Blockchain healthcare network to build a stable digital identity for healthcare institutions and providers. Combines Blockchain with IoT technologies to improve the responsiveness and traceability of the supply chain, thus making healthcare logistics more transparent for the proper monitoring of the patient.	[102–105]
11	Create research initiatives	Blockchains can allow a reliable information source. Blockchain can transform the manual mode of processing for membership claims and disputes. By exchanging patient data more generally, Blockchains may mobilise new and creative research initiatives. Further, the exchange of patient findings in greater depth will catalyse new and creative research,	[106–109]

(continued on next page)

Table 1 (continued)

S.No	Applications	Description	References
		leading to an extraordinary partnership between participants and researchers. This technology can also have a beneficial effect on the control of patient referrals. Once a patient consults the doctor and designs a therapy schedule, the therapy package will be applied as part of the patient care record to the Blockchain.	
12	Maintain financial statements in hospitals	It is crucial to maintain an accurate record of the financial statements in the bookkeeping process. The clinical trials are suitable for smooth operation and assessment. Here, Blockchain companies have invented methods of streamlining the accounting and reporting process. Through this application, everyone can prepare to go to a health care provider and complete the paperwork in advance. It will save time by preventing them from waiting in line. However, we can learn the risks and benefits from the practical uses of Blockchain and the type of problems it solves in the healthcare system.	[110–113]
13	Improves safety	Blockchain increases overall safety in the health treatment of patients, addresses medication validity and drug traceability problems, and allows for safe interoperability. It is the only way to replace the existing supply chain management scheme and prevent counterfeit drug manufacturers from bringing their drugs into the market with better safety. Regardless of the medical centres and organisations. Blockchains would allow all data to be stored centralised location. The interoperability of Blockchain technology will enable doctors to conveniently view the detailed medical records to help diagnose their diagnosis and develop a better and more precise operation.	[114–118]
14	Minimise data transformation time and cost	Blockchain networks minimise data transformation time and costs. Blockchain networks promise to solve the issue of fast and effective verification of medical credentials. Blockchain networks guarantee patient anonymity and protection. This will open up significant new ideas and findings that can change healthcare works in the world. Implementation of Blockchain will lead to valuable and privacy-respecting monetised data sharing networks. Blockchain is a distributed network computing technology that allows storing transaction history and documentation with time stamping. Each node in this network processes verifies and records each data input.	[119–123]

and must do more work for technology exploration and research. It, however, applies to medical associations and regulators' obligations. The time has come for the health sector to improve. Blockchain in the field of healthcare is very likely to expand in the future. Its applications in healthcare will improve with this technological innovation as it helps

explain the outcomes and progress in the treatment process. Blockchain technology is core to validating transactions and transfers of information.

In the upcoming days, with the consent of the network members, transactions can be authenticated and registered using Blockchain technologies. Blockchain will provide numerical security by public and private key encryption to the patient's level as the foundation of a new generation of health information sharing. This technology promises to treat patient records, infringement prevention, interoperability improvement, the rationalisation of procedures, medication and prescription control, and medical and supply chains monitoring. Blockchain in healthcare is seen with a tremendous performance in the future.

8. Conclusion

There are innovative applications of Blockchain in healthcare due to inherent encryption and decentralisation. It enhances the security of patients' electronic medical records, promotes the monetisation of health information, improves interoperability among healthcare organisations, and helps counterfeit combat medicines. Different healthcare fields can change with Blockchain technology; areas like healthcare, digital agreements allowed by intelligent contracts constitute one of Blockchain's most critical applications. By removing intermediaries from the payment chain, intelligent contracts will minimise costs. The Blockchain potential in healthcare depends significantly on the adoption of associated advanced technologies in the ecosystem. It includes system tracking, healthcare insurance, medicines tracing, and clinical trials. Hospitals can chart their services using a Blockchain framework, even over the entire life cycle, using device tracking. Blockchain technology can well be used to improve patient history management, especially tracking and the insurance mediation process, thereby accelerate clinical actions with optimised data maintenance. Overall, this technology would significantly enhance and eventually revolutionise how patients and physicians treat and use clinical records and improve healthcare services.

Conflict of interest

None.

References

- [1] S. Khezr, M. Moniruzzaman, A. Yassine, R. Benlamri, Blockchain technology in healthcare: a comprehensive review and directions for future research, *Appl. Sci.* 9 (9) (2019) 1736.
- [2] T. Kumar, V. Ramani, I. Ahmad, A. Braeken, E. Harjula, M. Ylianttila, Blockchain utilisation in healthcare: key requirements and challenges, in: *2018 IEEE 20th International Conference on E-Health Networking, Applications and Services (Healthcom)*, IEEE, 2018 Sep 17, pp. 1–7.
- [3] G. Moona, M. Jewariya, R. Sharma, Relevance of dimensional metrology in manufacturing industries, *MAPAN* 34 (2019) 97–104, <https://doi.org/10.1007/s12647-018-0291-3>.
- [4] M.H. Kassab, J. DeFranco, T. Malas, Giuseppe Destefanis Laplante, V.V. Neto, Exploring research in Blockchain for healthcare and a roadmap for the future, *IEEE Trans. Emerg. Top. Comput.* (2019), 1–1.
- [5] B. Shen, J. Guo, Y. Yang, MedChain: efficient healthcare data sharing via Blockchain, *Appl. Sci.* 9 (6) (2019) 1207.
- [6] U. Chelladurai, S. Pandian, A novel blockchain based electronic health record automation system for healthcare, *J. Ambient Intell. Humanized Comput.* (2021).
- [7] P. Zhang, D.C. Schmidt, J. White, G. Lenz, Blockchain technology use cases in healthcare, in: *Advances in Computers*, vol. 111, Elsevier, 2018 Jan 1, pp. 1–41.
- [8] I. Yaqoob, K. Salah, R. Jayaraman, Y. Al-Hammadi, Blockchain for healthcare data management: opportunities, challenges, and future recommendations, *Neural Comput. Appl.* (2021 Jan 7) 1–6.
- [9] X. Liang, J. Zhao, S. Shetty, J. Liu, D. Li, Integrating blockchain for data sharing and collaboration in mobile healthcare applications, in: *2017, IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, IEEE, 2017 Oct 8, pp. 1–5.
- [10] A. Varshney, N. Garg, K.S. Nagla, et al., Challenges in sensors technology for industry 4.0 for futuristic metrological applications, *MAPAN* 36 (2021) 215–226, <https://doi.org/10.1007/s12647-021-00453-1>.
- [11] T. McGhin, K.K. Choo, C.Z. Liu, D. He, Blockchain in healthcare applications: research challenges and opportunities, *J. Netw. Comput. Appl.* 135 (2019 Jun 1) 62–75.

- [12] X. Yue, H. Wang, D. Jin, M. Li, W. Jiang, Healthcare data gateways: found healthcare intelligence on Blockchain with novel privacy risk control, *J. Med. Syst.* 40 (10) (2016 Oct) 1–8.
- [13] M. Hölbl, M. Kompara, A. Kamišalić, L. Nemec Zlatolas, A systematic review of the use of Blockchain in healthcare, *Symmetry* 10 (10) (2018 Oct) 470.
- [14] A. Farouk, A. Alahmadi, S. Ghose, A. Mashatan, Blockchain platform for industrial healthcare: vision and future opportunities, *Comput. Commun.* 154 (2020 Mar 15) 223–235.
- [15] A. Ekblaw, A. Azaria, J.D. Halamka, A. Lippman, A Case Study for Blockchain in Healthcare: "MedRec" prototype for electronic health records and medical research data, in: *InProceedings of IEEE Open & Big Data Conference*, vol. 13, 2016 Aug 13, p. 13.
- [16] V. Dhillion, D. Metcalf, M. Hooper, Blockchain in healthcare, in: *Blockchain-enabled Applications*, Apress, Berkeley, CA, 2021, pp. 201–220.
- [17] D.V. Dimitrov, Blockchain applications for healthcare data management, *Healthcare informatics research* 25 (1) (2019 Jan) 51.
- [18] M. Mettler, Blockchain technology in healthcare: the revolution starts here, in: *In2016 IEEE 18th International Conference on E-Health Networking, Applications and Services (Healthcom)*, IEEE, 2016 Sep 14, pp. 1–3.
- [19] J. Chanchaichujit, A. Tan, F. Meng, S. Eaimkhong, Blockchain technology in healthcare, in: *healthcare 4.0*, Palgrave Pivot, Singapore, 2019, pp. 37–62.
- [20] G. Tripathi, M.A. Ahad, S. Paiva, S2HS-A Blockchain-based approach for smart healthcare system, in: *Healthcare*, vol. 8, Elsevier, 2020 Mar 1, p. 100391. No. 1.
- [21] R. Gupta, S. Tanwar, S. Tyagi, N. Kumar, M.S. Obaidat, B. Sadoun, Habits: blockchain-based telesurgery framework for healthcare 4.0, in: *In2019 International Conference on Computer, Information and Telecommunication Systems (CITS)*, IEEE, 2019 Aug 28, pp. 1–5.
- [22] G. Srivastava, R.M. Parizi, A. Dehghantanha, The future of blockchain technology in healthcare internet of things security, *Blockchain Cybersecurity, Trust and Privacy* (2020) 161–184.
- [23] M. Bhavin, S. Tanwar, N. Sharma, S. Tyagi, N. Kumar, Blockchain and quantum blind signature-based hybrid scheme for healthcare 5.0 applications, *Journal of Information Security and Applications* 56 (2021 Feb 1) 102673.
- [24] G. Rathee, A. Sharma, H. Saini, R. Kumar, R. Iqbal, A hybrid framework for multimedia data processing in IoT-healthcare using blockchain technology, *Multimed. Tool. Appl.* (2019 Jun 3) 1–23.
- [25] E. Chukwu, L. Garg, A systematic review of Blockchain in healthcare: frameworks, prototypes, and implementations, *IEEE Access* 8 (2020 Jan 28) 21196–21214.
- [26] B. Houtan, A.S. Hafid, D. Makrakis, A survey on blockchain-based self-sovereign patient identity in healthcare, *IEEE Access* 8 (2020 May 12) 90478–90494.
- [27] A. Rejeb, L. Bell, Potentials of blockchain for healthcare: case of Tunisia, *World Scientific News* 136 (2019) 173–193.
- [28] E.M. Abou-Nassar, A.M. Ilyasu, P.M. El-Kafrawy, O.Y. Song, A.K. Bashir, A.A. Abd El-Latif, DiTrust chain: towards blockchain-based trust models for sustainable healthcare IoT systems, *IEEE Access* 8 (2020 Jun 2) 11223–11238.
- [29] K. Paranjape, M. Parker, D. Houlding, J. Car, Implementation considerations for Blockchain in healthcare institutions, *Blockchain in Healthcare Today* 2 (2019 Jul 9) 10–30953.
- [30] T. Le Nguyen, Blockchain in healthcare: a new technology benefit for both patients and doctors, in: *In2018 Portland International Conference on Management of Engineering and Technology (PICMET)*, IEEE, 2018 Aug 19, pp. 1–6.
- [31] R. Kumar, N. Marchang, R. Tripathi, Distributed off-chain storage of patient diagnostic reports in healthcare system using IPFS and Blockchain, in: *In2020 International Conference on Communication Systems & NETWORKS (COMSNETS)*, IEEE, 2020 Jan 7, pp. 1–5.
- [32] M. Javaid, A. Haleem, R. Vaishya, S. Bahl, R. Suman, A. Vaish, Industry 4.0 technologies and their applications in fighting COVID-19 pandemic, *Diabetes & Metabolic Syndrome: Clin. Res. Rev.* 14 (4) (2020 Jul 1) 419–422.
- [33] L. Bell, W.J. Buchanan, J. Cameron, O. Lo, Applications of blockchain within healthcare, *Blockchain in healthcare today* 1 (8) (2018 Jul 9).
- [34] K. Miyachi, T.K. Mackey, hOCBS: a privacy-preserving blockchain framework for healthcare data leveraging an on-chain and off-chain system design, *Inf. Process. Manag.* 58 (3) (2021 May 1) 102535.
- [35] C. Esposito, A. De Santis, G. Tortora, H. Chang, K.K. Choo, Blockchain: a panacea for healthcare cloud-based data security and privacy? *IEEE Cloud Computing* 5 (1) (2018 Mar 28) 31–37.
- [36] K.A. Clauson, E.A. Breeden, C. Davidson, T.K. Mackey, Leveraging blockchain technology to enhance supply chain management in healthcare: an exploration of challenges and opportunities in the health supply chain, *Blockchain in healthcare today* 1 (3) (2018 Apr 11) 1–2.
- [37] I.A. Omar, R. Jayaraman, M.S. Debe, K. Salah, I. Yaqoob, M. Omar, Automating procurement contracts in the healthcare supply chain using blockchain smart contracts, *IEEE Access* 9 (2021 Feb 26) 37397–37409.
- [38] K. Yaeger, M. Martini, J. Rasouli, A. Costa, Emerging blockchain technology solutions for modern healthcare infrastructure, *Journal of Scientific Innovation in Medicine* 2 (1) (2019 Jan 24).
- [39] M.Z. Bhuiyan, A. Zaman, T. Wang, G. Wang, H. Tao, M.M. Hassan, Blockchain and big data to transform healthcare, *Proceedings of the International Conference on Data Processing and Applications* (2018 May 12) 62–68.
- [40] P. Pandey, R. Litoriya, Securing and authenticating healthcare records through blockchain technology, *Cryptologia* 44 (4) (2020 Jul 3) 341–356.
- [41] R. Abujamra, D. Randall, Blockchain applications in healthcare and the opportunities and the advancements due to the new information technology framework, in: *Advances in Computers*, vol. 115, Elsevier, 2019 Jan 1, pp. 141–154.
- [42] A. Mubarakali, Healthcare services monitoring in cloud using secure and robust healthcare-based BLOCKCHAIN (SRHB) approach, *Mobile Network. Appl.* 25 (4) (2020 Aug) 1330–1337.
- [43] A. Sharma, S. Bahl, A.K. Bagha, M. Javaid, D.K. Shukla, A. Haleem, Blockchain technology and its applications to combat COVID-19 pandemic, *Research on Biomedical Engineering* (2020 Oct 22) 1–8.
- [44] A.A. Abdellatif, A.Z. Al-Marridi, A. Mohamed, A. Erbad, C.F. Chiasserini, A. Refaey, ssHealth: toward secure, blockchain-enabled healthcare systems, *IEEE Network* 34 (4) (2020 Apr 22) 312–319.
- [45] T. Mikula, R.H. Jacobsen, Identity and access management with Blockchain in electronic healthcare records, in: *In2018 21st Euromicro Conference on Digital System Design (DSD)*, IEEE, 2018 Aug 29, pp. 699–706.
- [46] A. Shahnaz, U. Qamar, A. Khalid, Using blockchain for electronic health records, *IEEE Access* 7 (2019 Oct 9) 147782–147795.
- [47] R. Kumar, W. Wang, J. Kumar, T. Yang, A. Khan, W. Ali, I. Ali, An integration of blockchain and AI for secure data sharing and detection of CT images for the hospitals, *Comput. Med. Imag. Graph.* 87 (2021 Jan 1) 101812.
- [48] W.J. Gordon, C. Catalini, Blockchain technology for healthcare: facilitating the transition to patient-driven interoperability, *Comput. Struct. Biotechnol. J.* 16 (2018 Jan 1) 224–230.
- [49] A.A. Siyal, A.Z. Junejo, M. Zawish, K. Ahmed, A. Khalil, G. Soursou, Applications of blockchain technology in medicine and healthcare: challenges and future perspectives, *Cryptography* 3 (1) (2019 Mar) 3.
- [50] R. Kumar, R. Tripathi, Scalable and secure access control policy for healthcare system using Blockchain and enhanced Bell–LaPadula model, *Journal of Ambient Intelligence and Humanized Computing* 12 (2) (2021 Feb) 2321–2338.
- [51] J. Daniel, A. Sargolzaei, M. Abdelghani, S. Sargolzaei, B. Amaba, Blockchain technology, cognitive computing, and healthcare innovations, *J. Adv. Inf. Technol.* 8 (3) (2017 Aug).
- [52] R. Jayaraman, K. Salah, N. King, Improving opportunities in healthcare supply chain processes via the internet of things and blockchain technology, in: *International Journal of Healthcare Information Systems and Informatics (IJHISI)*, vol. 14, 2019 Apr 1, pp. 49–65, 2.
- [53] S. Chakraborty, S. Aich, H.C. Kim, A secure healthcare system design framework using blockchain technology, in: *In2019 21st International Conference on Advanced Communication Technology (ICACT)*, IEEE, 2019 Feb 17, pp. 260–264.
- [54] R.B. Fekih, M. Lahami, Application of blockchain technology in healthcare: a comprehensive study, in: *International Conference on Smart Homes and Health Telematics*, Springer, Cham, 2020 Jun 24, pp. 268–276.
- [55] S. Balasubramanian, V. Shukla, J.S. Sethi, N. Islam, R. Saloum, A readiness assessment framework for Blockchain adoption: a healthcare case study, *Technol. Forecast. Soc. Change* 165 (2021 Apr 1) 120536.
- [56] N. Tariq, A. Qamar, M. Asim, F.A. Khan, Blockchain and smart healthcare security: a survey, *Procedia Computer Science* 175 (2020 Jan 1) 615–620.
- [57] K.M. Hossein, M.E. Esmaeili, T. Dargahi, Blockchain-based privacy-preserving healthcare architecture, in: *In2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*, IEEE, 2019 May 5, pp. 1–4.
- [58] D.K. Aswal, Quality infrastructure of India and its importance for inclusive national growth, *MAPAN* 35 (2020) 139–150, <https://doi.org/10.1007/s12647-020-00376-3>.
- [59] A.D. Dwivedi, G. Srivastava, S. Dhar, R. Singh, A decentralised privacy-preserving healthcare blockchain for IoT, *Sensors* 19 (2) (2019 Jan) 326.
- [60] K.N. Griggs, O. Ossipova, C.P. Kohlios, A.N. Baccarini, E.A. Howson, T. Hayajneh, Healthcare blockchain system using smart contracts for secure automated remote patient monitoring, *J. Med. Syst.* 42 (7) (2018 Jul) 1–7.
- [61] J. Fu, N. Wang, Y. Cai, Privacy-preserving in healthcare blockchain systems based on lightweight message sharing, *Sensors* 20 (7) (2020 Jan) 1898.
- [62] K.P. Satamraju, Proof of concept of scalable integration of internet of things and Blockchain in healthcare, *Sensors* 20 (5) (2020 Jan) 1389.
- [63] M. Ejaz, T. Kumar, I. Kovacevic, M. Yliantila, E. Harjula, Health-BlockEdge: blockchain-edge framework for reliable low-latency digital healthcare applications, *Sensors* 21 (7) (2021 Jan) 2502.
- [64] E.J. De Aguiar, B.S. Façal, B. Krishnamachari, J. Ueyama, A survey of blockchain-based strategies for healthcare, *ACM Comput. Surv.* 53 (2) (2020 Mar 13) 1–27.
- [65] S. Aggarwal, N. Kumar, M. Alhussein, G. Muhammad, Blockchain-based UAV path planning for healthcare 4.0: current challenges and the way ahead, *IEEE Network* 35 (1) (2021 Feb 16) 20–29.
- [66] T.K. Mackey, T.T. Kuo, B. Gummadi, K.A. Clauson, G. Church, D. Grishin, K. Obbad, R. Barkovich, M. Palombini, 'Fit-for-purpose?'—challenges and opportunities for applications of blockchain technology in the future of healthcare, *BMC Med.* 17 (1) (2019 Dec) 1–7.
- [67] A. Khatoun, A blockchain-based innovative contract system for healthcare management, *Electronics* 9 (1) (2020 Jan) 94.
- [68] I. Abu-Elezz, A. Hassan, A. Nazeemudeen, M. Househ, A. Abd-Alrazaq, The benefits and threats of blockchain technology in healthcare: a scoping review, *Int. J. Med. Inf.* (2020 Aug 14) 104246.
- [69] R. Vaishya, M. Javaid, I.H. Khan, A. Vaish, K.P. Iyengar, Significant role of modern technologies for COVID-19 pandemic, *Journal of Industrial Integration and Management* (2021 Mar 4) 1–3.
- [70] H.M. Hussien, S.M. Yasin, N.I. Udzir, M.I. Ninggal, S. Salman, Blockchain technology in the healthcare industry: trends and opportunities, *Journal of Industrial Information Integration* 22 (2021 Jun 1) 100217.
- [71] R. Bhuvana, L.M. Madhushree, P.S. Aithal, Blockchain as a disruptive technology in healthcare and financial services-A review based analysis on current implementations, *International Journal of Applied Engineering and Management Letters (IJAEML)* 4 (1) (2020) 142–155.

- [72] M.M. Onik, S. Aich, J. Yang, C.S. Kim, H.C. Kim, Blockchain in healthcare: challenges and solutions, in: *Big Data Analytics for Intelligent Healthcare Management*, Academic Press, 2019 Jan 1, pp. 197–226.
- [73] C.C. Agbo, Q.H. Mahmoud, J.M. Eklund, Blockchain technology in healthcare: a systematic review, in: *Healthcare*, vol. 7, Multidisciplinary Digital Publishing Institute, 2019 Jun, p. 56, 2.
- [74] M.A. Engelhardt, Hitching healthcare to the chain: an introduction to blockchain technology in the healthcare sector, *Technology Innovation Management Review* 7 (10) (2017).
- [75] S. Tanwar, K. Parekh, R. Evans, Blockchain-based electronic healthcare record system for healthcare 4.0 applications, *Journal of Information Security and Applications* 50 (2020 Feb 1) 102407.
- [76] S. Wang, J. Wang, X. Wang, T. Qiu, Y. Yuan, L. Ouyang, Y. Guo, F.Y. Wang, Blockchain-powered parallel healthcare systems based on the ACP approach, *IEEE Transactions on Computational Social Systems* 5 (4) (2018 Aug 28) 942–950.
- [77] S. Jiang, J. Cao, H. Wu, Y. Yang, M. Ma, J. He, Blochie: a blockchain-based platform for healthcare information exchange, in: *2018 IEEE International Conference on Smart Computing (Smart Comp)*, IEEE, 2018 Jun 18, pp. 49–56.
- [78] P. Zhang, M.A. Walker, J. White, D.C. Schmidt, G. Lenz, Metrics for assessing blockchain-based healthcare decentralised apps, in: *In2017 IEEE 19th International Conference on E-Health Networking, Applications and Services (Healthcom)*, IEEE, 2017 Oct 12, pp. 1–4.
- [79] J. Hathaliya, P. Sharma, S. Tanwar, R. Gupta, Blockchain-based remote patient monitoring in healthcare 4.0, in: *In2019 IEEE 9th International Conference on Advanced Computing (IACC)*, IEEE, 2019 Dec 13, pp. 87–91.
- [80] D. Berdik, S. Otoum, N. Schmidt, D. Porter, Y. Jararweh, A survey on Blockchain for information systems management and security, *Inf. Process. Manag.* 58 (1) (2021 Jan 1) 102397.
- [81] X. Du, B. Chen, M. Ma, Y. Zhang, Research on the application of blockchain in smart healthcare: constructing a hierarchical framework, *Journal of Healthcare Engineering* (2021 Jan 12) 2021.
- [82] K. Peterson, R. Deeduvanu, P. Kanjamala, K. Boles, A blockchain-based approach to health information exchange networks, *InProc. NIST Workshop Blockchain Healthcare 1* (No. 1) (2016 Sep) 1–10.
- [83] A. Celesti, A. Ruggeri, M. Fazio, A. Galletta, M. Villari, A. Romano, Blockchain-based healthcare workflow for telemedical laboratory in federated hospital IoT clouds, *Sensors* 20 (9) (2020 Jan) 2590.
- [84] P. Zhang, M.N. Boulos, Blockchain solutions for healthcare, in: *Precision Medicine for Investigators, Practitioners and Providers*, Academic Press, 2020 Jan 1, pp. 519–524.
- [85] E. Gökalp, M.O. Gökalp, S. Çoban, P.E. Eren, Analysing opportunities and challenges of integrated blockchain technologies in healthcare, in: *InEurosymposium on Systems Analysis and Design*, Springer, Cham, 2018 Sep 20, pp. 174–183.
- [86] G. Leeming, J. Cunningham, J. Ainsworth, A ledger of me: personalising healthcare using blockchain technology, *Front. Med.* 6 (2019 Jul 24) 171.
- [87] M. Javaid, A. Haleem, Industry 4.0 applications in medical field: a brief review, *Current Medicine Research and Practice* 9 (3) (2019 May 1) 102–109.
- [88] P. Bhattacharya, S. Tanwar, U. Bodke, S. Tyagi, N. Kumar, Bindaas: blockchain-based deep-learning as-a-service in healthcare 4.0 applications, *IEEE Trans. Netw. Sci. Eng.* 8 (2) (2021) 1242–1255.
- [89] A. Al Omar, M.Z. Bhuiyan, A. Basu, S. Kiyomoto, M.S. Rahman, Privacy-friendly platform for healthcare data in cloud-based on blockchain environment, *Future Generat. Comput. Syst.* 95 (2019 Jun 1) 511–521.
- [90] M. Zarour, M.T. Ansari, M. Alenezi, A.K. Sarkar, M. Faizan, A. Agrawal, R. Kumar, R.A. Khan, Evaluating the impact of blockchain models for secure and trustworthy electronic healthcare records, *IEEE Access* 8 (2020 Aug 27) 157959–157973.
- [91] R. Ribitzky, J.S. Clair, D.I. Houlding, C.T. McFarlane, B. Ahier, M. Gould, H.L. Flannery, E. Pupo, K.A. Clauson, Pragmatic, interdisciplinary perspectives on Blockchain and distributed ledger technology: paving the future for healthcare, *Blockchain Healthc Today* 1 (2018 Mar 23) 24.
- [92] K. Khujamatov, E. Reypnazarov, N. Akhmedov, D. Khasanov, Blockchain for 5G healthcare architecture, in: *In2020 International Conference on Information Science and Communications Technologies (ICISCT)*, IEEE, 2020 Nov 4, pp. 1–5.
- [93] C.C. Agbo, Q.H. Mahmoud, Comparison of blockchain frameworks for healthcare applications, *Internet Technology Letters* 2 (5) (2019 Sep) e122.
- [94] Y. Sun, R. Zhang, X. Wang, K. Gao, L. Liu, A decentralising attribute-based signature for healthcare blockchain, in: *In2018 27th International Conference on Computer Communication and Networks (ICCCN)*, IEEE, 2018 Jul 30, pp. 1–9.
- [95] K. Zheng, Y. Liu, C. Dai, Y. Duan, X. Huang, Model checking PBFT consensus mechanism in healthcare blockchain network, in: *In2018 9th International Conference on Information Technology in Medicine and Education (ITME)*, IEEE, 2018 Oct 19, pp. 877–881.
- [96] H.L. Pham, T.H. Tran, Y. Nakashima, A secure remote healthcare system for hospital using blockchain smart contract, in: *In2018 IEEE Globecom Workshops (GC Wkshps)*, IEEE, 2018 Dec 9, pp. 1–6.
- [97] L. Ismail, H. Material, S. Zeaddally, Lightweight blockchain for healthcare, *IEEE Access* 7 (2019 Oct 15) 149935–149951.
- [98] A. Tandon, A. Dhir, N. Islam, M. Mäntymäki, Blockchain in healthcare: a systematic literature review, synthesising framework and future research agenda, *Comput. Ind.* 122 (2020 Nov 1) 103290.
- [99] C.C. Agbo, Q.H. Mahmoud, Blockchain in healthcare: opportunities, challenges, and possible solutions, *Int. J. Healthc. Inf. Syst. Inf.* 15 (3) (2020 Jul 1) 82–97.
- [100] F. Curbera, D.M. Dias, V. Simonyan, W.A. Yoon, A. Casella, Blockchain: an enabler for healthcare and life sciences transformation, *IBM J. Res. Dev.* 63 (2/3) (2019 Apr 26), 8–1.
- [101] G. Srivastava, J. Crichigno, S. Dhar, A light and secure healthcare blockchain for IoT medical devices, in: *In2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*, IEEE, 2019 May 5, pp. 1–5.
- [102] P.P. Ray, D. Dash, K. Salah, N. Kumar, Blockchain for IoT-based healthcare: background, consensus, platforms, and use cases, *IEEE Syst. J.* 15 (1) (2020 Jan 21) 85–94.
- [103] P. Mamoshina, L. Ojomoko, Y. Yanovich, A. Ostrovski, A. Botezatu, P. Prihodko, E. Izumchenko, A. Aliper, K. Romantsov, A. Zhebrak, I.O. Ogu, Converging Blockchain and next-generation artificial intelligence technologies to decentralise and accelerate biomedical research and healthcare, *Oncotarget* 9 (5) (2018 Jan 19) 5665.
- [104] D.J. Munoz, D.A. Constantinescu, R. Asenjo, L. Fuentes, Clinicappchain: a low-cost blockchain hyperledger solution for healthcare, in: *International Congress on Blockchain and Applications*, Springer, Cham, 2019 Jun 26, pp. 36–44.
- [105] L. Soltanisehat, R. Alizadeh, H. Hao, K.K. Choo, Technical, temporal, and spatial research challenges and opportunities in blockchain-based healthcare: a systematic literature review, *IEEE Trans. Eng. Manag.* (2020) 1–16.
- [106] M.A. Cyran, Blockchain as a foundation for sharing healthcare data, *Blockchain in Healthcare Today* 1 (2018 Mar 23) 1–6.
- [107] H.S. Chen, J.T. Jarrell, K.A. Carpenter, D.S. Cohen, X. Huang, Blockchain in healthcare: a patient-centred model, *Biomedical journal of scientific & technical research* 20 (3) (2019) 15017.
- [108] A.A. Mazlan, S.M. Daud, S.M. Sam, H. Abas, S.Z. Rasid, M.F. Yusof, Scalability challenges in healthcare blockchain system—a systematic review, *IEEE Access* 8 (2020 Jan 24) 23663–23673.
- [109] R. Vaishya, A. Haleem, A. Vaish, M. Javaid, Emerging technologies to combat the COVID-19 pandemic, *Journal of clinical and experimental hepatology* 10 (4) (2020 Jul 1) 409–411.
- [110] T.A. Syed, A. Alzahrani, S. Jan, M.S. Siddiqui, A. Nadeem, T. Alghamdi, A comparative analysis of blockchain architecture and its applications: problems and recommendations, *IEEE Access* 7 (2019 Dec 4) 176838–176869.
- [111] A. Al Omar, M.S. Rahman, A. Basu, S. Kiyomoto, Medibchain: a Blockchain-based privacy-preserving platform for healthcare data, in: *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*, Springer, Cham, 2017 Dec 12, pp. 534–543.
- [112] R.W. Ahmad, K. Salah, R. Jayaraman, I. Yaqoob, S. Ellahham, M. Omar, The role of blockchain technology in telehealth and telemedicine, *Int. J. Med. Inf.* (2021 Jan 28) 104399.
- [113] V. Ramani, T. Kumar, A. Bracken, M. Liyanage, M. Yliantila, Secure and efficient data accessibility in Blockchain-based healthcare systems, in: *In2018 IEEE Global Communications Conference (GLOBECOM)*, IEEE, 2018 Dec 9, pp. 206–212.
- [114] D.C. Nguyen, P.N. Pathirana, M. Ding, A. Seneviratne, BEdgeHealth: a decentralised architecture for edge-based IoT networks using blockchain, *IEEE Internet Things J.* 8 (14) (2021) 11743–11757.
- [115] M.J. Gul, B. Subramanian, A. Paul, J. Kim, Blockchain for public health care in smart society, *Microprocess. Microsyst.* 80 (2021 Feb 1) 103524.
- [116] A. Islam, S.Y. Shin, A blockchain-based secure healthcare scheme with the assistance of unmanned aerial vehicles in the Internet of Things, *Comput. Electr. Eng.* 84 (2020 Jun 1) 106627.
- [117] D. Dhagarra, M. Goswami, P.R. Sarma, A. Choudhury, Big Data and blockchain supported conceptual model for enhanced healthcare coverage, *Bus. Process Manag. J.* (2019).
- [118] N. Islam, Y. Faheem, I.U. Din, M. Talha, M. Guizani, M. Khalil, A blockchain-based fog computing framework for activity recognition as an application to e-Healthcare services, *Future Generat. Comput. Syst.* 100 (2019 Nov 1) 569–578.
- [119] S. Angraal, H.M. Krumholz, W.L. Schulz, Blockchain technology: applications in health care, *Circulation: Cardiovascular Quality and outcomes* 10 (9) (2017 Sep), e003800.
- [120] A. Saha, R. Amin, S. Kunal, S. Vollala, S.K. Dwivedi, Review on "Blockchain technology-based medical healthcare system with privacy issues, Security and Privacy 2 (5) (2019 Sep) e83.
- [121] P. Pandey, R. Litoriya, Implementing healthcare services on a large scale: challenges and remedies based on blockchain technology, *Health Policy and Technology* 9 (1) (2020 Mar 1) 69–78.
- [122] K.A. Koshechkin, G.S. Klimenko, I.V. Ryabkov, P.B. Kozhin, Scope for the application of blockchain in the public healthcare of the Russian federation, *Procedia Computer Science* 126 (2018 Jan 1) 1323–1328.
- [123] R. Ashima, A. Haleem, S. Bahl, M. Javaid, S.K. Mahla, S. Singh, Automation and manufacturing of smart materials in Additive Manufacturing technologies using Internet of Things towards the adoption of Industry 4.0, *Mater. Today: Proceedings* 45 (2021) 5081–5088.
- [124] N. Kshetri, Blockchain and electronic healthcare records [cybertrust], *Computer* 51 (12) (2018) 59–63.
- [125] M.C. Wong, K.C. Yee, C. Nohr, Socio-technical consideration for blockchain technology in healthcare, *Stud. Health Technol. Inf.* 247 (2018) 636–640.
- [126] S. Rab, S. Yadav, N. Garg, et al., Evolution of measurement system and SI units in India, *MAPAN* 35 (2020) 475–490, <https://doi.org/10.1007/s12647-020-00400-6>.
- [127] M. Javaid, A. Haleem, R.P. Singh, S. Khan, R. Suman, Blockchain technology applications for Industry 4.0: a literature-based review, *BLOCK: Research and Applications* (2021 Aug 12) 100027.
- [128] H.M. Hussien, S.M. Yasin, S.N. Udizir, A.A. Zaidan, B.B. Zaidan, A systematic review for enabling of develop a blockchain technology in healthcare application: taxonomy, substantially analysis, motivations, challenges, recommendations and future direction, *J. Med. Syst.* 43 (10) (2019) 1–35.