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REVIEW

Blockchain technology in healthcare: Challenges and opportunities

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ABSTRACT

Patients and healthcare practitioners are faced with the challenge of accessing, managing, integrating, and sharing health records securely. Patients should be able to manage their health records anywhere in the world, keep track of medical background, give access to data, and share those with any healthcare professional securely. Direct access to data for patients and a more robust data-sharing infrastructure could better prepare the healthcare system to manage public health threats during the emergence of deadly disease outbreak such as COVID-19. Current technologies in use by the healthcare industry do not adequately address these requirements due to limitations related to privacy, security, and full ecosystem interoperability. This paper conducted a literature review to find out the pivotal roles blockchain technology play in solving some of the most critical and challenging issues facing the healthcare industry. This paper identifies challenges and opportunities for implementing blockchain technology in healthcare and summarizes health-related blockchain products and key players offering solutions across different applications. In doing this, our research extends and complements existing blockchain research in healthcare.

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Blockchain; Peer-to-Peer network; Compliance tracking; healthcare data; cyber security; HIPPA compliant Transform; on-Chain data management

1. Introduction

A significant challenge for the healthcare industry is proper management and safe retrieval of the massive amount of personal health data generates by the normal activities of conducting business and providing services. Healthcare monitoring technologies, including wearables, also generate massive amounts of personal health data. Health data is mostly inaccessible, non-standardized across systems, and challenging to understand, use, and share. They are pulled from diverse sources and are stored in centralized IT systems that make managing and sharing a challenging task. Requesting, sending, receiving, and compiling patient data are time-consuming and require excessive resources [1]. Proper management and safe retrieval of these data enable healthcare systems to create holistic views of patients, improve the quality of care and treatments, enhance communication, and improve health outcomes [2].

Another problem facing the healthcare industry is interoperability, inaccessible medical records, and lack of comprehensive and secure population health data. The recent Public health crises further highlight the lack of interoperability in the current healthcare system [3]. Finally, the security of healthcare data is a significant issue for the healthcare industry. Many healthcare organizations store valuable health information in a central location in an aging legacy IT infrastructure that is a prime target for ransomware and other cyberattacks [3].

There has been a recent push towards patient-driven interoperability, in which health data exchange is patient-driven [4]. However, the healthcare industry is still in the beginning stages of developing infrastructure, computer programs, and strategic methods that can bring together the different types of data available to them on a reliable, secure, and consistent basis [5]. Existing healthcare data systems have several limitations, including patients' privacy, data integrity, quality, and accuracy. The healthcare industry is looking for opportunities provided by different technologies to resolve some of these critical challenges. As such, a novel technology that could facilitate the shift to patient-centered interoperability is in high demand. Blockchain technology can help solve some of healthcare's interoperability challenges and can play a critical role in putting patients at the center of the ecosystem [6].

Research about blockchain and healthcare is currently limited [7]. Current literature provides little overview of applications that have been developed, tested, and/or deployed. As blockchain applications become more mainstream, it is essential to examine whether the blockchain-enabled healthcare system improves health outcomes and lowers chronic disease risk within our communities. The remainder of this paper is organized as follows: Section two presents a background of blockchain technology with a description of its key elements. Section three discusses challenges facing the healthcare industry and reviews

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potential benefits of blockchains and the crucial roles this technology play in solving some of the most critical issues in the healthcare industry, including accessibility and security of patient information. Section 4 outlines technical, organizational, and behavioral challenges of implementing the blockchain-enabled healthcare system. Blockchain use cases and emerging blockchain-based solutions for healthcare are also presented in this section. Finally, section 5 presents a summary and conclusions.

2. Blockchain technology defined

Blockchain technology is one of the most important innovations of this century. It not only provides operational and regulatory verification efficiencies; it also enhances tractability and visibility throughout the supply chain of many industries [8]. Distributed ledger technology (DLT), known as 'blockchain', has captured the imaginations and wallets of the financial services institutions [9]. A blockchain is a decentralized, continuously growing list of records, called 'blocks', that are linked together in the chain through a process called mining. This process turns pending transactions into a mathematical puzzle. Miners (people) solve the puzzle using computer systems and produce what is called a hash – a sequence of letters and numbers unique to the block [10]. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data. It also contains information from all previous blocks and transactions to create a network or chain. If the data inside any one of the blocks changes, it sets up a chain reaction that could freeze up the whole blockchain. Once the blockchain processes the information, every computer in the network locks in at the same time, creating a permanent, immutable digital record. Each blockchain system determines who can add new blocks to the chain and how the procedure is done [11]. The unique advantages of blockchain are that it allows sharing data and transactions on an immutable P2P network to enhance transparency, security, and [12]. Blockchain has been largely used for cryptocurrency and financial transactions. However, other industries, including entertainment, manufacturing, and healthcare, are adopting blockchain technology to leverage its benefits of enhanced security as well as privacy [13].

Blockchain will help solve some of the healthcare's interoperability challenges and can play a critical role in putting patients at the center of the ecosystem [6]. It enhances security, privacy, interoperability, and can put patients at the center of the ecosystem [14]. In summary, blockchain can be applied to the accessing and sharing of patient medical records, mobile applications and remote monitoring, and medical data management system that allows patients to retain ownership over their records [7]. Section 4 reviews blockchain application in healthcare and discuss how technology can address some of the challenges and issues facing the industry.

3. Critical challenges and blockchain solutions

The U.S. health care industry is the world's largest and absorbs more than $1.7 trillion per year [15]. Today, the average annual cost of healthcare per person in America is $10,739, which is more than residents of any other country. The amount spent on healthcare is nearly 18 percent of the Growth Domestic Product (GDP). It is projected that with no change, in 2027, the healthcare industry will consume nearly 20 percent of the U.S. GDP [16]. The healthcare industry is implementing strategies and tactics to address the growth of medical and pharmaceutical costs and improve the quality of care.

Faced with critical challenges, issues, and opportunities provided by technology, the healthcare industry is changing rapidly in several ways. First, it is no longer the alliance between big pharma, big government, and trained medical professionals. Tech giants are getting into the industry intending to implement strategies and tactics to address the growth of medical and pharmaceutical costs and to impact access and quality of care. Consumer health is a growing target of these companies' massive R&D investments. Second, the existing healthcare system takes care of us after we get sick, treating symptoms, not preventing root causes. COVID-19 may be speeding up the trend of continuous healthcare, where richly layered data-driven decisions are replacing what we have today. Lastly, wearables introduced by Apple, Google, Amazon, and other tech companies continuously monitor individual health parameters, including body temperature, heart rate, respiratory sounds, heart rate variability, walking steps, 24/7 by sensors. The data and health parameters gathered by these devices could later be analyzed, accounting for what you eat, how you sleep, and any set of behaviors. Software created by these companies aimed to improve patients' lives holistically, monitoring how we live, our daily routines, and preventive guidance informed by digital health research. In the latest COVID-driven initiative, Apple and Google will be launching a comprehensive Bluetooth-based opt-in contact tracing technology. The plan is to implement complete contact tracing through voluntarily shared mass consumer data, tracking individual movements, and precise interactions between followed users and their health data [17].

Any technology approach to improving healthcare must consider actual needs from the diverse perspectives of consumers, patients, providers, and regulators

and be responsive to the unique challenges faced in healthcare compared to other sectors of the economy. Various stakeholders aggressively explore blockchain to optimize business processes, lower costs, improve patient outcomes, enhance compliance, and enable better use of healthcare-related data [18]. Interest in the blockchain-enabled healthcare system is exploding. In an IBM study of over 200 life sciences executives in 18 countries, more than 70 percent of respondents expect that blockchain will help them overcome inefficient bureaucratic processes and legacy systems that slow down their ability to innovate and adapt [19]. In 2019, Anthem, the second-largest health insurer, announced that it would use blockchain technology to store patient health data for 40 million patients [20].

Table 1 provides a summary of the potentials and applications of blockchain technology in healthcare and life sciences [13,19,21–23]. The detailed review of the roles blockchain could play in helping the healthcare data management issues are discussed in the following sections.

3.1. Data collection and storage

Healthcare monitoring technologies, including wearables, generate massive amounts of personal health data. Proper management and safe retrieval of these data are crucial for data-driven decisions in our healthcare system. Our existing healthcare system also generates data by the normal activities of conducting business and providing services. Patients interact with numbers of health care providers through the course of their lives, leaving data scattered across a provider's system. Providers often retain primary data stewardship and create a fragmented data trail and decaying ease of access for patients. Healthcare data is characterized by a large volume, heterogeneity, and speed. They are non-uniform, have many variables, and need real-time data analysis. This data is mostly inaccessible, non-standardized across systems, and challenging to understand, use, and share [4].

3.1.1. Current status of healthcare record-keeping and medical history

The following are characteristics of the current healthcare records keeping and data collection systems [6,14,24].

- It relies on the interaction between patient and physician
- It keeps failing to take advantage of the data
- It creates a long and tedious process of getting healthcare

Table 1. Blockchain potentials for healthcare and life sciences.

Categories	Potential Use	Key Benefits
Patient	• Patient empowerment • Patients can keep track of their medical background • Patients can check their latest medical prescriptions • Patients can share their data securely across their providers	• Increases patient trust • Improves patient access to trusted data • Facilitates better collaboration • Increases transparency • Improves and personalizes the patient experience • Increases efficiency and reduces operations costs • Enables patient access to their health records anywhere in the world • Enables patient access to their latest prescriptions
Regulation and Compliance	• Compliance tracking • Smart contract-based check	• Establishes a trusted audit trail verifiable in real-time • Establishes a platform to enforce privacy regulations automatically • Enables monitoring of who has shared data and with whom, without revealing the data itself
Intercompany Process	• Transfer of funds • Medical devices supply chain • Temperature-controlled supply chains • Services	• Facilitates automated payments through smart contracts • Increases speed for payments • Provides full transparency of assets across the supply chain to the patient • Enables certified & private messaging between medical devices and service providers • Brings all transactions into a single platform
Administration and Back Offices	• Revenue management	• Improves efficiencies in tracking and tracing areas where leakage occurs • Reduces admin costs • Increases reliability and auditability • Speeds up financial transactions process
Pharmaceuticals	• Verifies drug provenance • Creates an industry-wide, single source of aggregate information	• Tracks and traces pharmaceuticals • Proof of authenticity for anti-counterfeiting techniques • Helps prevent the transport and sale of counterfeit products • Makes it is possible to detect the full spectrum of complications related to pharmaceutical treatment
Research & Development	• Securing clinical trials	• Prevents theft of intellectual property • Enables users to authenticate any document and ensuring proof of the existence • Enables access to a huge anonymous and authenticated database of patients

Sources: [19,22,23].

- Critical patient information is scattered all over the systems
- It lacks critical data availability, therefore, many healthcare systems fail to provide the necessary treatment to the patients
- It negatively impacts management system as many players are not equipped with the right information for a smooth process
- It provides poor healthcare data security and reliability

The healthcare industry is very inefficient, where most medical records are still stored on paper and distributed locations. They cannot be used to coordinate care, measure quality, or reduce medical errors [15]. Healthcare data are digitally collected in diverse points. It is important to extract the best benefits out of this healthcare data without complicating the processes. A crucial challenge facing the healthcare industry is the ability to record and store information easily and economically and share it securely across disparate applications and systems [2]. The portability of data and uniform compatibility while working across diverse systems is also essential [22].

3.1.2. Blockchain solutions for healthcare record keeping

Blockchain technology is suitable for any kind of digital data where authentication and consensus about data integrity are important, and where shared write access for several parties is necessary. Blockchain can be used to keep important medical data safe and secure [25]. Blockchain can provide a solution to recordkeeping problems in the healthcare industry, and it is particularly useful for recording continuous and steady growth of transactions. Blockchain is more appropriate for an open consumer transaction environment where the older information is less important and where data growth is continuous and steady [26]. Blockchain technology is being considered for securing DNA data, personal information, healthcare records, and essential medical history information. Healthcare providers can use blockchain to store details about patients' records where patients and doctors can directly check those records through the network, anytime, anywhere [27].

Blockchain enables uniform portability and multifaceted protection system across different phases. It enables health providers to create an integrated health records system where patients are at the center, owning the private key to their data. Patients control who can access or use their data. The blockchain-powered integrated system helps in the reconciliation of records and activities as well as help in curbing fraud. The system will also help patients to access and manage their health records anywhere in the world; share those records with any healthcare professional securely; and keep track of their medical background such as allergies, chronic diseases, and vaccines [2].

A recent study proposed a blockchain-based data preservation system for medical data that can provide a reliable storage solution to ensure the primitiveness and verifiability of stored data while preserving privacy for users. The prosed data system enables users to preserve important data in perpetuity. The originality of the data can be verified if tampering is suspected [28]. Another study proposed a blockchain-based secure and privacy-preserving personal health information sharing system for diagnosis improvements in e-Health systems. Due to its advantages of immutability, blockchain can help to improve the accuracy of diagnosis, where security and privacy preservation are critical issues in the systems [29].

3.2. Data sharing and interoperability

Inefficient interoperability creates two types of problems [5]: the difficulty of identifying patients and information blocking where healthcare providers are imposing an unreasonable constraint on the exchange of patient data or electronic health information. Lack of universally recognized patient identifiers and information blocking practices are a huge detriment to efficient healthcare practice. Furthermore, interoperability matters, particularly in an outbreak like the corona pandemic. The timing of the outbreak underscores the dire need for a more robust data-sharing infrastructure that could help streamline patient-provider communication and ease the flow of information to manage public health threats. Patients need to have easy access to their medical records if they visit doctors who are not their primary care physician. Additionally, improving the flow of health data would enable doctors to perform remote monitoring and telemedicine consult. That empowers patients to keep their doctors informed of their medical history [3]. As cases of the coronavirus mount, expedient and transparent information, including information on how patients may assess their risk, present symptoms, and respond to treatment, become crucial. Public health crises further highlight the lack of interoperability in the current system [3].

3.2.1. Existing data sharing

Medical records are digitally stored in a centralized IT system that makes sharing difficult. Requesting, sending, receiving, and compiling patient data is tedious, time-consuming, and costly. Tech development in medical data management has been very slow due to regulations, incompatible backend systems, and fragmented shared medical information. The lack of collaboration and data sharing between the healthcare storage systems makes it difficult to transmit, retrieve, and analyze data. As a result, most of the data is

contained in silos databases and limit patients' ability to engage with their medical history [2].

3.2.2. Blockchain solutions for data sharing

Blockchain technology could make the process of sharing healthcare data significantly easier and can help end the interoperability problem in the healthcare industry. In the permissioned healthcare blockchain, the patients are identified via their hash ID, which will be their unique identifier. The hashing allows the ID to be unique and secures the privacy of the user. Patients would oversee sharing the decryption key for their own associated blocks of data with their chosen healthcare provider(s). It enhances security, privacy, interoperability, and could put patients at the center of the ecosystem [14]. Patients and providers would greatly benefit from accurate, up-to-date, and comprehensive medical records.

3.3. Data security and identity management

Concerns surrounding data security and patient privacy are fueled by recent security breaches in patient healthcare records. According to global cybersecurity insurance company Beazley, 45 percent of the ransomware attacks in 2017 targeted healthcare organizations [30]. The number of hacked healthcare records and medical data breaches is on the rise. According to the HIPPA Journal, the number of reported breaches in the healthcare industry rose from below 20 in 2009 to more than 350 in 2017 [31]. According to the Department of Health and Human Services, in 2018, the number of breaches in the healthcare industry resulted in the exposure of 13 million total healthcare records [32]. Health data breaches averaged at least one per day, affecting more than 27 million patient records in 2016 [33]. In 2018, hackers exposed sensitive medical records of 1.4 million patients from the UnityPoint Health hospital network. This was considered the largest medical data breach in the U.S. that year. The hacked records included lab results, treatments, patient's social security numbers, and insurance information [31].

3.3.1. Existing data security issues

Many healthcare organizations store valuable health information in a central location in an aging legacy IT infrastructure that is a prime target for ransomware and other cyberattacks [2]. Healthcare organizations are often the targets of sophisticated cyber-attacks due to the depth of information stored by healthcare providers. Loss of access to patient records and other critical information can be crippling to any provider costing victim organizations millions of dollars. Healthcare organizations are investing in advanced security technologies like better data backups, advanced data encryption, AI, and real-time security platforms to prevent threats before they start posing serious issues [30]. Concerns surrounding data security and patient privacy and the rise in the number of cyberattacks have created a pressing need for better IT security. Healthcare organizations are investing in advanced security technologies like better data backups, advanced data encryption, AI, and real-time security platforms to prevent threats before they start posing serious issues [30].

3.3.2. Blockchain solutions for data security and identity management

Blockchain can provide several advantages for healthcare data security and identity management [34]. It can curb threats and keeps private data out of the wrong hands. Blockchain encrypts data when added to the chain and make it immutable and impossible to decipher. It authorizes transactions with a private identification key, known only to the individual. Thus, unlike the healthcare data technology of today, a healthcare provider would be able to access a patient's medical data only with explicit access to the blockchain record [22]. Better data collaboration between providers increases the probability of an accurate diagnosis and the likelihood of successful treatments and enables healthcare facilities to deliver cost-effective care. Blockchain can keep patient information safe and secure while still enable them to share it with any service providers of their choice. It provides proof of ownership of medical records, and guarantee authenticity for anti-counterfeiting techniques [23].

According to a recent study conducted by BIS research, by 2025, the healthcare industry could save up to $100 billion per year by incorporating the blockchain technology. The saving will be realized in a reduction in data breach-related costs, operations costs, IT costs, counterfeit-related frauds, and insurance frauds. The report states that global applications of blockchain in the healthcare market are expected to grow at a compound annual growth rate of nearly 64 percent from 2018 to 2025. It will reach a value of nearly six billion by 2025 [35].

3.4. The need for socioeconomic database

Clinicians and researchers have recognized the importance of the relationship between socioeconomic factors and individual health. They believe that purely individual characteristics may not capture all determinants of health status fully [36]. Socioeconomic data is focused on environmental, social, and communal factors. It plays an essential role in the development of health management programs that address the specific range of needs for a certain group of people. Socioeconomic data is a rich source for public health professionals allowing them to consider the type and

frequency of illegal drug use, incidents of interpersonal violence, and economic disparities at the state, county, and city levels [36]. Moreover, complete, and accurate socioeconomic data will become increasingly important to reduce disparities between different socioeconomic and ethnic groups. This data is essential if providers are to have a chance of implementing effective population health management strategies [37]. Another key socially rooted data for health informatics professionals is claims data that include dates of specific care, diagnosis codes, and cost. This data act as a basis for healthcare professionals to better gauge whom they are treating and which major health issues they are facing. Finally, prescription medication data allows healthcare professionals and policymakers to determine how patients are managing chronic health problems and diseases. A robust public health system that can collect, store, score, and protect population health data is needed in the healthcare industry.

3.4.1. Existing socioeconomic data and blockchain solutions

Institute of Medicine and the National Quality Forum primarily focus on collecting socioeconomic and health behavior data directly from individual patients. In 2014 both entities recommended the inclusion of social determinants of health data in electronic health records (EHRs) if providers are to have a chance of implementing effective population health management strategies [37]. Collecting such information reliably, accurately, and consistently is a substantial task, and it may take several years before a primary care provider has actionable data available in its HER [37]. Blockchain technology can solve the challenges of data sharing, privacy agreements, and the maintenance of data integrity, quality, and accuracy and speed up the availability of actionable socioeconomic and behavioral health data into EHRs.

3.5. Blockchain solutions for financial and records

Billing inaccuracies and frauds are the major issues in healthcare billing. Blockchain can help address these issues using decentralized records keeping helping payment processing and preventing forged transactions. Blockchain technology supports a feature called smart contracts. Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code and exist across a distributed decentralized blockchain network [38]. A smart contract resides on a specific place on the blockchain with a unique address. Nodes invoke the contract by sending cryptocurrency to the address, and then the consensus protocol takes care of the verification process [39]. Important features of smart contracts are no need for the third party, improved traceability, and improved security [28].

Furthermore, using smart contracts blockchain could permit a more efficient value-based healthcare payment model where the common mistrust between physicians and payers is eliminated. Additionally, reimbursement or financial penalty can be tied to specific health parameters within the blockchain medical record, thus removing human error from enforcing value-based payments [22]. Smart contracts could also notify the patient's insurance company about billing and claim settlements and, in the process, increasing effectiveness in fraud detection and pricing and reducing administrative cost [40].

Finally, blockchain can help insurance companies as it brings transparent information about transactions and creates a sense of trust. Blockchain can also improve claims processing by taking inputs from a variety of different sources without tampering with any information [40]. A blockchain framework can provide a reliable medical insurance storage solution to ensure the primitiveness and verifiability of stored data while providing high credibility to users [41].

3.6. Blockchain solutions for pharmaceuticals

3.6.1. Drug traceability

Another major problem facing the healthcare industry is the drug counterfeit problem, where over 15% of drugs sold in developing countries are counterfeit. Pharmaceutical companies lose about $200 billion annually due to counterfeiting [24]. Blockchain can solve the counterfeit drug problem by providing visibility, security, and drug traceability. The technology uses features like proof of authenticity and point-by-point tracking possibilities to curb the counterfeit problem, ensuring that once a drug is produced that it is genuine. The user can verify the authenticity of the drugs before purchasing them [42]. Blockchain not only can be used to track the drugs from its manufacturing until its delivery to the patient but also it can record a drug effect on patient to a database after the usage for future statistics [42].

3.6.2. Clinical trials

Clinical trials, a method of testing a new drug and its effectiveness in a controlled environment, produce tons of data. The process is expensive, takes a few years to complete, and not without fraud. It is crucial to have a transparent solution that lets anyone review the clinical reports and ensure that the results of the trial are not tampered with. Blockchain can be a great technology to facilitate clinical trials by providing data integrity, and the authenticity of the documents needs to be verified. The distributed network

ensures that no data can be modified without authorized access [24].

3.6.3. Healthcare supply chain

Pharmaceutical enterprises are using blockchain to track the journey of raw materials, compounds, or components at every step of the supply chain, from the original source to the patient [24]. Pharmaceutical research communities can also use blockchain for securing medical and health-related supply chain data. Blockchain is seen as improving the ability to identify the origin and authenticity of medical products, which improves supply chain security [43–45]. Blockchain also makes it possible to detect the full spectrum of complications related to pharmaceutical treatment, as controlled substance abuse is becoming more common.

Blockchain-based technology is used to share data in a more trusted way in the pharmaceutical industry. One such example is the Modum.io, a Zurich-based start-up company, that combines sensors and blockchain technology to improve pharma supply-chain efficiency [46]. With the help of SAP Software Solutions and Swiss Post, Modum.io developed MODSense, a blockchain-based solution that offers temperature monitoring within the pharma supply chain for sensitive products. MODSense ensures that the recorded temperatures cannot be tampered with and that stakeholders know how a certain product was handled during transportation [46]. The solution can be applied to a wide range of things, including medical supplies, transportation of vaccines, clinical trials, medical samples, and perishable foods. In another example, the pharmaceutical company Bayer developed a blockchain solution to track materials through its supply chain ecosystem. The solution identified the whereabouts of product faster than usual and helped achieve a higher level of efficiency and security within the pharmaceutical supply claim [47].

3.7. Public Health

COVID-19 outbreak highlighted the importance of population health data, which is broadly defined as information related to the health outcomes of specific groups of people. Population health, the analysis of health outcomes of large groups of people, is becoming an effective and increasingly utilized tool in efforts to treat widespread health problems, promote good health practices, and discourage drug and alcohol abuse. Affordable Care Act (ACA) promoted concepts that are essential to population health: a team approach to better coordinating care in practices and among providers, and care that is focused on engaging patients and providing better quality [48]. Without such a robust population health record system that would instantly give relevant organizations the information they need about potential outbreaks, it is difficult to perform the analytics solutions that are needed to map the impact of and behavior of the COVID-19 outbreak [3]. Blockchain could play an important role in the success of public healthcare initiatives. With the help of distributed ledger technology, the blockchain proactively promotes collaboration of various parties involved and facilitate deep insights into vital healthcare trends.

Another public issue concern is healthcare issues associated with opioid overdose that has become epidemic. Blockchain technology can create an industry-wide, single source of aggregate information about any controlled substance purchase for each dispenser. With such information, the seller can use analytics to determine how many opioids are too many for a dispenser to order [19].

3.8. Organ transplant

Another example of how blockchain is transforming the healthcare industry is in the area of organ transplants. Organ transplants are complicated. Organs deteriorate quickly, and donated organs must be from someone with a compatible blood type. According to the University of Michigan Transplant Center, a heart or lung is usually transplanted in less than 10 h. Without an efficient system, lifesaving organs are going to waste. More than 120,000 people are on the waiting list for an organ transplant, where on average, 22 of those people die every day. Organtree is the world's first decentralized organ donation database company using blockchain technology to connect donors, patients, and healthcare facilities. Blockchain enables Organtree to increase the number of matches and make the transplants much faster and simpler than before [49].

United Arab Emirates (UAE) is the first country in the world that will use blockchain and AI for an organ transplant. UAE partnered with Dhonor Healthtech; a leading national company focused on global healthcare blockchain solutions. The main objective is to provide a safer and optimized organ donation procedure. Further objectives are to build the standards that will improve organ verification, the matching of organs with patients, and transplant optimization using AI and blockchain. Blockchain and AI enable hospitals to optimize the process of matching organs from donors to patients [50].

4. Strategic values and implementation challenges

Blockchain technology is new and has not been adopted by all industries. There are not many successful blockchain technology models out there. This

creates uncertain situations and impacts the overall decision to select blockchain technology for future growth. However, blockchain technology could be evaluated and judged based on its own merit of being a foundational technology and meeting innovation challenges, as discussed in detail in the following sections.

4.1. Meeting innovation challenges and offering opportunities

According to MIT, winning companies innovate because they integrate the needs of people, the possibilities of technology, and the requirements for business success. These companies blend the perspectives of marketing, design, and engineering into a systematic approach to delivering innovation [51]. Their product and services reflect the following three criteria (Figure 1):

- Technical: Does a better solution exist? Does this solution give us a competitive advantage?
- People: Is there a real unmet need? How important is this need?
- Business: Is it financially viable? Is it effective and cost-efficient?

Blockchain technology is a great solution for the healthcare industry, meeting all the above three requirements of innovation challenges. It is technically feasible, desirable by patients, and a viable solution for healthcare providers. As discussed in this paper, blockchain is a viable technology that results in an integrated healthcare information system [22]. It maintains traceable records of distributed data and work. The technology perfectly handles diverse healthcare data challenges and helps in extracting the maximum output from the data collected on diverse levels [52].

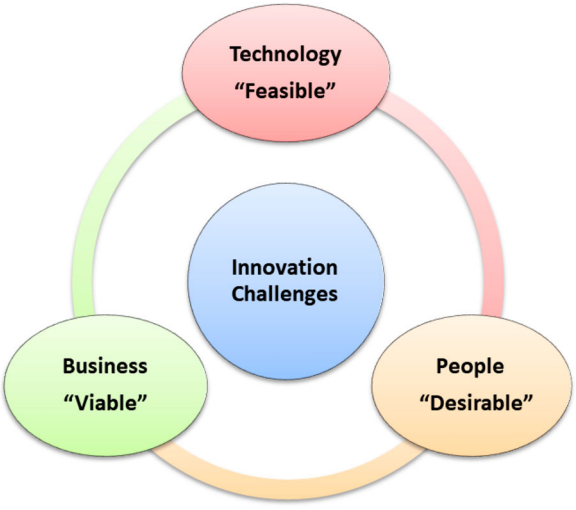

Figure 1. Innovation challenges.

Implementation of blockchain in healthcare addresses four major issues: fragmented data, slow access to medical data; system interoperability; patient agency; and improved data quality and quantity for medical research [53]. Also, recent technological advances in the Blockchain technology and a robust industry-wide commitment to standards and security point to a bright future for blockchain in healthcare [22]. Figure 2 summarizes factors that have contributed to the overall popularity of the blockchain-based healthcare market.

4.2. Emerging blockchain-based healthcare solutions

Several companies have begun the development and distribution of blockchain technologies for the healthcare industry. The blockchain-based platform and software provided by these companies provide different types of solutions, including helping the healthcare industry to store digital records securely, improving the way medical data is shared and used, protecting the integrity of health records, and offering a solution to drug traceability and counterfeiting. Table 2 summarizes health related Blockchain products and key players offering proprietary blockchain solutions across the different applications [54–56].

4.3. Implementation challenges and barriers to adoption

A recent study analyzed the literature to find advantages, disadvantages, and challenges of adopting blockchain technology in healthcare from people, process technology perspectives.

Blockchain advantages were flexible, adaptable, agile, and secure infrastructure with high performance and low latency. The distributed network also provides a unified and secured view and exchange of electronic health records. Disadvantages were cost, complexity, hype, uncertainty about this technology, and patients' lack of awareness of this new technology [57]. Other studies identified 'lack of evaluation in a real-world setting', in addition to legal, social, and

Figure 2. Strategic values of blockchain-based healthcare.

Table 2. Emerging blockchain solutions for healthcare.

Company/ Platform	Industry	Applications
MEDREC	• Big Data • Cybersecurity • Software	• Uses blockchain for electronic medical records • It is designed to manage authentication, confidentiality, and data sharing
BURSTIQ	• Big Data • Cybersecurity • Software	• Uses blockchain to improve the way medical data is shared and used • It is a HIPPA compliant platform used by large enterprises and government agencies for on-chain data management, complex data ownership, and granular consent
FACTOM	• Enterprise Software • Information Tech	• Employs blockchain technology to help the healthcare industry securely store digital records on the company's blockchain platform
MEDICALCHAIN	• Electronic Health Record • Medical	• Employs a blockchain-based platform that protects the integrity of health records and maintains a record of the origin and protects the patient identity
GUARDTIME	• Cybersecurity • Blockchain	• It helps healthcare companies and governments implement blockchain into their cybersecurity methods
ROBOMED	• Blockchain • Medicine	• It uses blockchain to securely gather patient information and share it with a patient's healthcare providers
PATIONTORY	• Blockchain • Cybersecurity • Healthcare • Information Tech.	• Uses blockchain platform for the secure storage and transfer of important medical information
BLOCKPHARMA	• Blockchain • Pharmaceuticals • Supply Chain	• It uses blockchain technology and offers a solution to drug traceability and counterfeiting
NANOVISION	• Blockchain • Cybersecurity	• Combines the power of blockchain with AI to gather data from traditional data silos and incompatible records systems
TIERION	• Blockchain • SaaS	• The company uses blockchain to audits documents, records and medicines to keep a clear history of possession and to maintain proof of ownership throughout a medical supply chain
CONECTINGCARE	• Cybersecurity • Blockchain	• Tracks the progress of patients after they leave the hospital
NEBULA GENOMICS	• Biotechnology • Genetics	• The company uses blockchain to eliminate unnecessary spending and middlemen in the genetic studying process

Sources: [54–56].

technological limitations among barriers of the adoption [22,58]. Another study researched the potential challenges and proposed solutions for adopting blockchain technology in biomedical/health care domains [13].

Blockchain is still a very new technology for many industries. As such, numerous obstacles stand in the way of its speedy deployment. Enterprises are not quite sure how to scale blockchain technology. Scholars and experts are quick to point out that the new blockchain-based technology is not a cure-all for what ails many industries [53,57]. For blockchain technology to work effectively, many barriers – technological, governance, organizational, and even societal – will have to fall. They believe blockchain is not a 'disruptive' technology; rather, it is a foundational technology – it has the potential to create new foundations for our economic and social systems [9]. Whether considered as 'revolutionary' or 'disruptive', blockchain approaches must be responsive to the unique healthcare needs from the diverse perspectives of consumers, patients, providers, and regulators [18].

Table 3 summarizes challenges facing the successful implementation of blockchain technology in the healthcare industry [6,18,21,22,52,59,60]. These challenges are further discussed in the following sections.

4.3.1. Technical

Blockchain software is still in its infancy, and it is being developed and refined. The technology must be adopted and integrated overtime and will incur initial greater costs to institutions [22]. Lack of scalability, non-standardization, the potential for information decay, integration with existing legacy systems needs to also be addressed. A related issue is a long time that it takes to verify new transactions on blockchain [5]. Other technical problems of implementation are the need for a network of interconnected computers (nodes) to supply the computing power necessary to create blocks once a transaction is submitted, unproven systems, and a hidden cost of operating such a system. It is known that a blockchain consumes significant computing power to process transactions, and the cost is derived from the

Table 3. Challenges of Developing blockchain-Based Healthcare.

Levels	Challenges
Technical	• Blockchain software is still in its infancy-being developed and refined • Lack of storage capacity for a large amount of data • Existence of a network of interconnected computers (nodes) to supply computing power to create blocks • Non-standardization and lack of scalability • Potential for information decay • Challenges with throughput capacity and storage limits • Integration challenges when corporate legacy systems and systems of record are involved • Requires selection of a blockchain protocol – the framework that guides the structure of the blockchain and development of applications
Organizational	• Cultural and trust concerns to adopt blockchain • Encouraging organizations to adopt technology and participate in a shared network • Interoperability issues • Unknown cost of operating blockchain • Challenges in finding the ROI
Drivers for Adoption	• Hesitant social adoption of technology • Lack of successful examples of blockchain-based projects • Uncertainty around adopting the technology and participate in a shared network • Knowledge Gap
Government Regulations/ Privacy	• The implication of the distributed storage nature of the blockchain • Lack of regulation that addresses the unique properties of blockchain data exchange • Ownership of records • How is access granted • Emerging cybersecurity concerns must be addressed before patients can entrust data to a public blockchain

Sources: [6,18,21,22,52,59,60].

volume and size of transactions submitted through the network [60]. Before transitioning the current electronic health system to blockchain-based technology, issues related to set up for hardware, software, implementation, and support needs to be assessed [61]. Another disadvantage of blockchain is that it is not ideal for data with high temporal resolution. The technology has issues with handling multi-dimensional data, such as complex text, images, and graphs [60].

4.3.2. Organizational

The existing Electronic Health Record (EHR) maintains detailed accounts of health information, and it is generated by a patient's healthcare providers across the industry. Several academic universities and other large health systems have poured millions of dollars into EHR in large part incentivized by the federal government. To ask hospitals, clinics, and physician offices to remove their current record system and replace it with a blockchain digital ledger is not economical at this point [52]. The incentives to use blockchain technology to create this extensive network of connected 'blocks' of data as a national record-keeping framework to replace our current system is not there yet. Blockchain could not completely replace the current system but could augment it. Most of the healthcare information would be kept off the blockchain. However, each 'block' would keep a small amount of information to describe a specific patient or procedure [6]. Another issue to tackle is to determine how to store current record data on the blockchain. We need to find common ground and agree to store all demographic information in a nationally recognized standard format. Organizations should align on a framework for defining what data, size, and format that can be submitted [62]. Finally, as it is the case with the implementation of new technology, the organizational issues related to the implementation of blockchain, particularly the management of employees involved within the organizational change process, cannot be ignored [62].

4.3.3. Regulations and privacy

Government regulations and culture are found to be among the fundamental drawbacks of blockchain technology. Government institutions have not yet settled regulatory concerns over blockchain, and culture adoption of the technology will require significant buy-in from the global healthcare participants [22].

4.4. Drivers for adoption

There is the unknown cost of operating blockchain and are challenges in finding the ROI. The business benefits that blockchain-based healthcare system offers will not arrive with a big bang. There is also a question regarding the 'drivers' for adaptation. There must be an incentive for health providers to adopt the technology. A return on investment (ROI) is not always a straightforward calculation [63]. Blockchain will not be a panacea for all the current medical record tribulations, nor can it be immediately applied. However, blockchain could improve the efficiency of the number of niche areas in the current healthcare system [6,63].

5. Summary and conclusions

This literature review found that the research on the explorative use of blockchain in healthcare is in its infancy, but the number of proposed solutions currently is growing exponentially. This article presented blockchain technology as a paradigm changer with its innovative approach to decentralized management, enhanced security, and immutable audit trail. The paper also explored the different blockchain use cases and applications in healthcare. The result indicates that blockchain can improve access control, interoperability, provenance, and data integrity in healthcare. Blockchain's distributed nature, transparent information structure, and immutable records keeping and stored across all participating users can help reduce the cost of these operations. The paper concluded that the technology could be used to securely coordinate and combine information from multiple providers, improve patient engagement, help to ensure availability of patient information, allow direct and secure communication between patients and providers, and encourage family health management. Additionally, ledger technology can manage the medicine supply chain and help healthcare researchers unlock genetic code.

Early applications of blockchain in healthcare have shown that successful implementation requires redefining the relations of all involved players from healthcare providers to patients and the pharmaceutical industry. Before redesigning the healthcare system with blockchain, issues related to blockchain technology, and legal and regulatory issues need to be addressed. Blockchain in healthcare today is in its infant stage, but it holds much promise for the healthcare industry. While the technology has not been universally adopted in the healthcare sector yet, its application will only be going to broaden in the future. In terms of future research, there is a scarcity of studies on the subject; more research in real case applications is needed.

5.1. Implications for practice

Although the journey towards the blockchain-based healthcare system has already begun, there have been very few reported examples of the business benefits realized by leading-edge healthcare enterprises resulting from this new technology. This dearth of reporting has led to incomplete data with effects that are often anecdotal and notably, not thoroughly tested. This paper shared views from a multidisciplinary group of practitioners at the forefront of blockchain conceptualization, development, and deployment. The outcome will help researchers in identifying the areas within the healthcare system, where blockchain is the most desirable and can be implemented.

Purpose

The purpose of this study is to do a literature review to explore the practical implications and identify the benefits and drawbacks of the use of blockchain technology in the healthcare industry.

Design/methodology/approach

This paper conducted a literature review and searched for papers that contained the word 'blockchain in healthcare' in their titles, keywords, or abstracts. The review of past work focused on identifying areas where blockchain has been utilized or proposed to be utilized in healthcare management. Papers were selected form the EBSCO Applied Science & Technology Source, the Web of Science, the EBSCO database, and a variety of Internet sites, including ResearchGate, and Google Scholar. Forty recent manuscripts were identified from selected papers between 2016 and 2020 to conduct the review and to outline the benefits and drawbacks of blockchain-based technology in the healthcare industry. Only English written articles were included, and priorities were given to health-related journals. The outcome of the review is a descriptive insight and a summary of blockchain capabilities and their impact on healthcare organization performance. The results also point to the scarcity of research on the theme and lack of work in practice.

Research limitations

There are not many papers published in peer-reviewed academic journals or written as academic working papers exploring the advantages and the limitations of the healthcare industry implementing blockchain technology. This paper is an academic contribution to a field dominated by the narratives and promises of consultants. The main limitation of this research is that the results were related to the mention of the term 'blockchain in healthcare' and not about technologies related to the healthcare industry.

Practical implications

The results of this study identify 12 products and key players offering proprietary blockchain solutions for the healthcare industry. Based on the business applications presented in this paper, practitioners will learn blockchain use cases and business potentials for the healthcare industry, strategic values and challenges addressed by blockchain, drivers for change, barriers to entry, and critical areas of concern regarding the adaptation of blockchain technology into healthcare organizations.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributor

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