LEVERAGING BLOCKCHAIN FOR SECURE AND TRANSPARENT HEALTHCARE DATA MANAGEMENT: ENHANCING PATIENT PRIVACY AND INTEROPERABILITY IN MEDICAL SYSTEMS

Faran Ali, MS/MPhil Economics, Riphah International College, Lahore, Pakistan. Email: faran.ali@ric.edu.pk

Asmatullah, Dept of Management Science, Qurtaba University, DI Khan, Pakistan. Email: asmateco1431@gmail.com

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Abstract. *The healthcare sector is undergoing significant digital innovation, but issues with data security, patient privacy, and interoperability persist. Blockchain technology, with its decentralized, transparent, and immutable nature, offers a potential solution. This study explores blockchain's applicability in addressing healthcare data management limitations, focusing on patient privacy protection and cross-hospital interoperability. Our solution utilizes blockchain to provide a secure data repository, empower patients with data access permissions, and enable efficient data sharing. The analysis highlights blockchain's benefits in mitigating data breaches and optimizing data sharing, while also addressing regulatory and technological challenges. A roadmap for successful implementation is presented, demonstrating blockchain's potential to enhance healthcare data handling. By leveraging blockchain technology, we can create a more secure, efficient, and patient-centric healthcare system. This study contributes to the growing body of research on blockchain's applications in healthcare, highlighting its potential for transformative impact.*

Keywords: Blockchain; Patient data management; Patient privacy; Transparency; Smart contract; Healthcare information systems

Introduction

The medical field is increasingly becoming digitized – technology has enabled a vast expansion in the amount of healthcare data (2). This explosion of data generation and users has created huge concerns related to the management, security, privacy and the interoperability of the data. The large and secure storage of large amount of sensitive data is now a major topic of interest for healthcare systems around the world (Mettler 2016). These challenges are especially important in electronic health s (EHRs), which have

been widely adopted as tools to capture patient-centric data. The EHR systems aim essentially to enhance quality of care and facilitate better health care delivery, but they offer associated new challenges regarding data privacy, security and information sharing (Bates et al., 2014).

One of the problems with current systems of healthcare is dependence on centralized databases. Although these databases are usually maintained by health care providers, or other third parties, they are a major point of vulnerability. Centralized systems are at risk for attacks, leaks, and hacking. Recent, well-publicized healthcare data breaches have exposed the vulnerability of patient data when it is stored in a central repository (Ponemon Institute, 2020). Centralization also leads to lack of continuity in the patient record and security issues. While patients' data is archived in different systems that are spread among different healthcare providers, completing all the relevant information or maintaining a concise record may be difficult for patient care (Ahrens et al., 2020). The fragmentation of medical data also presents barriers for healthcare professionals who need access to a holistic view of an individual's medical story, which could lead to misdiagnosis, delay in treatment, or, even, unnecessary testing (HIMSS, 2017).

Yet the growing need for interoperability—in other words, the capacity for multiple healthcare IT systems to exchange and use data in an easy-to-understand and consistent way—only serves to further complicate the day-to-day processes of healthcare data (Ahrens et al., 2020). Difficulty in interoperability arises due to no common standards between multiple systems and the proprietary nature of most of the healthcare technologies. With the increasing complexity of healthcare systems, the strong requirement for coherent information among heterogeneous systems such as electronic medical records, laboratory systems, medical image systems become essential. Interoperability in IT systems is needed for the flow of data among various healthcare organizations and for healthcare organizations to have seamless access to a patient's medical record, which could potentially delay a diagnosis and treatment (Bates et al., 2014). Also, the data is spread throughout different source systems, which means that it is cumbersome to do population health management and that health care in general is less efficient.

Blockchain, as a distributed digital ledger system for recording data in a secure, transparent and immutable manner, is believed to have a promising solution to these challenges. This distributed control enabled by blockchain also means that none of the participants owns all of the data, in a way that is more secure and transparent to the participants than centralized databases. All transactions are recorded as a "block" into the blockchain and is essentially impossible to alter or delete making the information permanent (Nakamoto, 2008). The cryptological nature of blockchain also increases the level of security because the data is encrypted; it can only be accessed by those who

are authorized (Mettler, 2016). More importantly, the fore listed features could make blockchain particularly powerful in addressing problems in data management within healthcare settings with considerations to data privacy, security, and integrity being the central attention.

Moreover, the use of blockchain does not actually need to maintain data protection, but can also achieve an extended level of interoperability, proposing a common and decentralized model for data exchange between different repositories. Blockchain and Distributed Ledger Giving providers, patients, and others the ability to access and exchange patient information easily in real-time irrespective of the system and platform they use. This capability can significantly reduce fragmentation by creating an integrated patient record that can be accessed by clinicians in real-time. Blockchain allows the automation of processes such as the consent for the sharing of medical data, which in-process provides access to the sensitive patient's information to specific few individuals or organizations due to the automation process energized by the smart contracts (Zohar et al., 2021). Thus, blockchain can lay the foundation of a more efficient exchange of healthcare data, ultimately resulting in better patient care and outcomes.

This research explores blockchain's potential in healthcare data management, focusing on security, privacy, and interoperability. It provides a comprehensive analysis of blockchain's benefits, challenges, and future applications in healthcare, highlighting its potential to revolutionize patient data management and improve healthcare outcomes.

Literature Review

Blockchain A blockchain is a distributed ledger system that records data in blocks that are shared across a network of computers, or nodes. Every block contains a set of transactions and once recorded cannot be changed, hence maintaining integrity and consistency of the data (Nakamoto, 2008). It is this immutability characteristic, in particular, which distinguishes blockchain from conventional centralized databases. All blockchain network members have a copy of the distributed ledger and being a decentralized system there is no centrally intermediate organization, thus providing more security and transparency (Swan, 2015). The point that explains the blockchain technology is that there are no single points for failure and therefore less prone to cyber-attacks and falsification processes (Zohar et al., 2021).

Using cryptographic security and consensus protocols to ensure data integrity are two important features of blockchain and are valuable in its use in healthcare. According to Mettler (2016), these consensus mechanisms (proof of work (PoW)/proof of stake (PoS)) of the blockchain create a situation where transactions seem to be validated by numerous nodes within

the network thereby minimizing the chances of fraudulent activities. Furthermore, the public and private key encryption would ensure the data in the blockchain is secure, and can only be accessed by the authorized members (Narayan, 2019). These characteristics make blockchain a perfect way to storage and share securely the data, particularly in the areas where the data integrity and privacy are important, such as in the healthcare field.

In the health sector, blockchain application in healthcare to enhance security of data and privacy has been examined in various studies (Saeed, et al., 2022). Zohar et al. (2021) also describe that blockchain uses its cryptographic features to secure health data against unauthorized access and change. Once information is uploaded to the blockchain, it's made secure and verifiable, since this data can't be manipulated in the future. This is very crucial in patient's privacy and to avoid un-authorized modifications on the record.

It goes without saying that the most important part of healthcare is to keep patient data stored securely and ensure patient privacy is maintained, considering how private and sensitive medical information can be. Says the World Health Organization (2019), the leakage of healthcare data, does not only affect patient privacy, but is able to and have negative influence over patient care, resulting in misdiagnoses and poor treatment. Securing applications that could benefit from being managed using blockchain within a security system is possible as the users access encrypted and consensus-based data that cannot be accessed or changed by unauthorized actors (Mettler, 2016). Blockchain and asymmetric encryption By using asymmetric encryption processes, the blockchain capability to encrypt data at the end-user level guarantees only the direct recipient may decrypt and access sensitive medical information (Narayan, 2019).

One of the key benefits of blockchain in healthcare is that it can offer patients control over their own data. Patients can use this to store their health records in an encrypted and secure digital wallet, to which access can be given to or withdrawn from healthcare providers, when the patient wants. This affords the patient the more empowered capability to decide who can see their health information in the first place, leading to better privacy (Zohar et al., 2021). By having this level of control over health status data, privacy laws such as Health Insurance Portability and Accountability Act (HIPAA) in the U.S., and General Data Protection Regulation (GDPR) in the EU, are met (Mettler, 2016).

It is obvious that Blockchain can also be the ultimate answer to the short comings of the current system as there are a lot of cases of data breaches that exist in the present centralized databases in health care (Ahrens et al.,2020). The healthcare sector is one of the costliest industries for data breaches, as indicated by Ponemon Institute (2020).

Blockchain can help reduce these risks by allowing us to record and share patient information on a secure and unmodifiable platform. Because of the fact that all transactions are kept on a transparent and unchangeable ledger, Blockchain allows for real-time auditing of data exchanges and it improves the accountability and integrity of the data (Taherdoost, 2023). Such a time-stamped and auditable healthcare transaction ledger holds healthcare entities accountable for any access or changes in data, which in turn helps improve and enhance data security.

Interoperability is the bane of the health data world. Healthcare is awash in disconnected data; providers maintain silos of information that can be hard to cross-reference across facilities (Ahrens et al., 2020). The existing data exchange among healthcare providers and institutions (e.g., EHRs) does not follow standing protocols, making it difficult to seamlessly share information (Bates et al., 2014). Lead In theory, blockchain technology could serve as a solution, as it provides a standardized and decentralized system for secure transmission of medical information between multiple providers and systems (Mettler, 2016).

The distributed ledger of 'blockchain' means all additions and changes to patient records can be seen and verified by approved parties, making the information sharing process more efficient, legitimate and transparent. The transparency of the ledger also prevents record duplication and ensures correctness of the patient data (Zohar et al., 2021). Secondly, utilizing blockchain can enhance healthcare data interoperability through the ability to share data instantly amongst geographically diverse healthcare professionals, lessening any delays in diagnosis or treatment (Narayan, 2019).

Smart contracts, contracts whose terms are embedded directly in code, contracts that self-execute are another important feature of blockchain that will help enable more interconnection in healthcare. Smart contracts can be used to automatically mediated the exchange of patient data, like patient consent. These contracts can also implement data access policies, such that only permissioned parties may view particular fragments of health data. Therefore, the blockchain not only optimizes the efficiency of the data exchange, but also ensures that the data access protocols of healthcare systems are followed (Zohar et al., 2021). This degree of automation can save time and improve accuracy of manual data entry, along with decreasing administrative overhead and automating workflows in health care facilities.

Furthermore, the shared, indelible nature of blockchain-based healthcare transactions can contribute to the ultimate goal of a fully interoperable healthcare ecosystem. With greater blockchain adoption in healthcare, systems might soon enjoy enough interoperability to trade data between systems and enable patients, who need to make good informed decisions, especially in

times of medical emergency (Ahrens et al 2020), access to an integrated real-time patient history spanning multiple sources.

Methodology

This work is of a qualitative nature and, using systematic literature review (SLR) as a research method, aims to investigate the potential areas of the healthcare domain where such a ledger may be proved promising. The study systematically summarizes academic articles, case reports, industry reports, and pilot studies on the application of the blockchain in healthcare (Saeed, et al., 2022). The emphasis is given to the applications directed towards improving the security of data, the privacy of patients, and the interoperability of the system (Taherdoost, 2023). We benefit from a comprehensive picture of the current state of blockchain technology in health care and its in- practice application (Mettler, 2016; Ahrens et al., 2020).

Related Work Here, the researcher categorically reviews previous work of applying blockchain in the hospital, pharmaceutical industry and telemedicine in healthcare. The research is a mapping of healthcare cases in which it has worked for organisations to deploy blockchain, in order to find good practices and learn from failures. In particular, the literature looks at the implementation of the blockchain technology for the recording of patients' data, the optimization of pharmaceutical supply chain transparency, and facilitating secure health data exchange between various providers and systems (Zohar et al. 2021; Bates et al. 2014).

Real-world examples are included to illustrate the challenges and opportunities, in terms of healthcare costs, scalability and patient care. Another conceptual model of how blockchain can be implemented into the current healthcare system is introduced that discusses the technical and legal requirements in addition the anticipated working environment to facilitate a smooth application (Saeed, et al., 2022). This model considers the technology standards of blockchain interoperability, regulatory compliance challenges, and the need of cooperation among stakeholders (Narayan, 2019).

The research also delves into some of the barriers to blockchain adoption, including unwillingness to change, lack of technical expertise and non-interoperability between blockchain and conventional health IT systems. Finally, it is hoped that, based upon the findings of the literature and currently available applications, this study will offer prospective healthcare organizations, which are envisioning the block chain technology as part of the solution, with guidelines to pursue for management of their data.

Results and Discussion

Privacy is crucially important especially in healthcare. Patient data is extremely sensitive, comprising data on the person and confidential health information, the protection of which is legally required in strict regulations,

such as Health Insurance Portability and Accountability Act (HIPAA) in the USA, and the General Data Protection Regulation (GDPR) in the European Union (Zohar et al., 2021). The incorporation of blockchain into healthcare will vastly improve patient privacy as patient records will be safeguarded, tamper-resistant and under the control of patient (Taherdoost, 2023).

Immutability as a unique characteristic of blockchain Immunity is the core factor for blockchain to realize patient data security. If a record is added to a blockchain, it cannot be changed or deleted without being detected, leaving a permanent, unforgeable record. Therefore, blockchain becomes applicable to secure medical data and prevent unauthorized dissemination of the data that also prevent false records (Narayan, 2019). Considering that blockchain stores the records on different nodes in a community network, and no one owns the data, you will also benefit from minimal reliance on central points of failure as well as increased security. This decentralized and encryption-protected system serves as a powerful barrier to hackers trying to break in and get a hold of such private patient information (Mettler, 2016).

And blockchain can help patients take control of their health information. Conventional patient data are saved in hospital, clinic, or third-party vendor owned centralized systems, managing data without any involvement of or knowledge by the patients (Mettler, 2016). A new blockchain-based system would also give patients the ability to manage their own medical data within a secure digital wallet, allowing them to give and remove temporary access to healthcare providers when they need to. This model introduces a consent-based framework for data access, through which a patient can determine which entities can access their health data (Zohar et al., 2021). Moreover, in real-time patient-controlled consent – as enabled through blockchain – could help with compliance to regulatory standards such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) that imposes a high value on patient autonomy and consent regarding sharing of data (Narayan, 2019).

Encryption features of blockchain provides a very high level of security and it protects sensitive information at all times. In traditional centralized systems, even if encryption is applied, the data resides in a single location and is thus susceptible to attacks (Mettler, 2016). With blockchain, on the other hand, information would be encrypted at the source and distributed over several nodes, thus minimizing the danger of unauthorized access and fostering the anonymization of patient data (Zohar et al., 2021). Blockchains have the capacity to guard data with complex encryption and the feature will help patients maintain access and managing their own data is a quantum leap in the realm of patient privacy and maintaining confidentiality.

And furthermore, with blockchain to store healthcare data, healthcare provider can prove the integrity of patient records in a clear way. This transparence not only can make certain that the data is real, it also helps foster trust between patients and providers. All the transactions (including read and write operations) are tracked and stored on the blockchain, which enables both patients and health professionals to review and confirm that no unauthorized modifications were applied (Narayan, 2019). This increased flow of information transparency promotes a secure environment in which patient privacy is maintained but where the right people can get the right information for the right treatment.

Blockchain and the Protection Against Data Breaches

Safeguarding health data from breaches and unauthorized access is an important challenge faced by healthcare systems globally. The average cost of data breach, however, remains above $7 million to the industry, as reported in the 2020 Ponemon Institute study. Centralized systems A heightened danger of data breaches is posed to centralized systems that store large amounts of private patient health information in one database.

The decentralized architecture of Blockchain is a potential solution to this problem. Because patient information is spread across many nodes, there's no one giant database that can be invalidated in one fell swoop. Because each node has a copy of the blockchain, it is significantly more difficult for bad actors to access the data and make changes to it without being caught. In addition, the security of the blockchain guarantees that the data is cryptographically encrypted in such a way that only the holders of the appropriate keys can access it, therefore, reducing the potential for data breach (Mettler, 2016).

Similarly, the immutable properties of blockchain mean that once placed on it, data cannot be tampered or removed without appropriate permissions. Such capabilities add extra security by ensuring the data cannot be tampered with or destroyed by hackers following an attack. However, all the action taken, or a change made to the data, is recorded in an open ledger that serves as an audit trail to be used to monitor in real time and to identify and prevent unauthorized actions (Narayan, 2019).

So, by improving data security and minimizing the risk of a breach, blockchain has a key role to play in enhancing patient privacy and preventing sensitive healthcare data from being compromised by cyberattacks. Healthcare could be the one of the biggest beneficiaries given that blockchain can offer secure, immutable, and transparent records which are less prone to unauthorized access and tampering.

Enhance The Interoperability Of Healthcare Data

The health care industry faces a significant interoperability problem. Healthcare data is frequently locked within silos across institutions, systems, and even providers and prevents the seamless sharing and exchange of data across the healthcare ecosystem. Data fragmentation results in waste, delay in medical diagnosis and treatment, and difficulty coordinating care (Bates et al., 2014). Interoperable healthcare systems are expected to enable to achieve better patient outcomes, better patient safety, better healthcare delivery, and the constraint of costs by avoiding redundant tests and treatments.

Such issues of interoperability are attempted to be fixed by the blockchain technology, which provides a decentralized and standardized infrastructure for data sharing. Distributed nature of blockchain allows that information from decentralized health care systems can be exchanged securely and in real time, despite of the type of used technology and platform (Mettler, 2016). This level of interoperability ensures that a patient's full medical history is available to any care provider, even if that patient's health record lives across several institutions and/or systems. In summary, blockchain enables instant sharing of information among caregivers to support timely, higher quality diagnoses and treatments.

Smart contracts are one of the important characteristics of blockchain that can enhance interoperability. Smart contracts are types of contracts that get executed without the particular dependence on the people involved. In the context of health information exchange, smart contracts can be used to share patient records across healthcare providers (Zohar et al., 2021). For example, a smart contract could automatically transfer a patient's medical records to a specialist when he approves it with such records being released only when due and under certain conditions. We can thus relieve to an extent administrative work from the healthcare provider by integrating this process into a automated one and even be compliant with privacy regulation as the procedure is motivated by the smart contract conditions.

Smart contracts may also implement data access policies, and limit the access to the individual patient's data to only trusted users or systems. It maintains security of the data as well as permits it to be shared fast and safely in conformity to compulsory rules (Narayan, 2019). By allowing the secure and self-governing access to information on a patient's medical records across multiple providers, blockchain can streamline patient care, leading to reduced wait times for treatment and better patient health, while still protecting patients' sensitive information.

And the Blockchain adds the control needed to make data exchanges traceable and controllable. Each of these transactions or data transfer through

blockchain is entered into the ledger and it makes the record keeping a transparent and tamper evident records of all activities carried out (Zohar et al., 2021). Key to accountability and trust in health, this level of transparency is particularly critical. By using block chain as a measure of authenticity anyone in blockchain healthcare can see how and when information is being used to make sure that sharing is legal and ethical.

Blockchain can decrease administrative healthcare costs by automating manual processes and streamlining the speed of data exchange. In the context of typical healthcare systems, data sharing is frequently completed via manual efforts (e.g. faxing medical records or submitting forms when a request for data is made). These processes are cumbersome, error prone, and expensive. Blockchain in healthcare data management can automate many of these manual processes and free the healthcare provider from administrative challenges, giving them the opportunity to concentrate on providing care (Mettler, 2016)

For instance, blockchain can automate patient identity verification and authorization to medical records. Typically, in existing systems, this may involve a series of relatively slow validations and other procedures to determine the patient's identity and entitlement to access particular documents. Since blockchain is decentralized, patient identification is securely maintained and easily verified, avoiding delays in retrieving medical records and speeding up the pace of data sharing (Zohar et al., 2021).

In addition, blockchain's real-time data sharing provides healthcare providers with instant access to current patient information—crucial when time is of the essence. It eliminates the need for unnecessary tests and procedures because providers can get the entire picture of a patient's conditions at a point of care making the entire healthcare system more efficient and less costly (Mettler, 2016).

The advantages that blockchain technology can bring in the healthcare industry are plenty, especially for patient privacy and data interoperability. In offering secure, tamper-proof records and placing patients in charge of their information, blockchain promises to revolutionize the secrecy and security of healthcare data. And blockchain's decentralized nature and cryptographic capabilities provide an added layer of security against data breaches and unauthorized access, so that patient data is protected.

Scalable solutions based on distributed ledgers such as Blockchain can provide a framework for secure data exchange with healthcare vendors and other systems and encourage data interoperability and efficient data transactions that reduce administrative cost and expedite data transactions. With smart contracts, the automation of health processes will be greater; parties can share data more easily.

Whichever way, there continue to be challenges in blockchain adaptation in the health space, some include regulation and integration of blockchain into existing system but the rewards are on a bigger scale. And with its emphasis on sensitive data privacy, patient data protection and healthcare data interoperability, the blockchain promises to transform the management of healthcare data, and become a factor in patient experience and care delivery.

Research Implication

This research has both theoretical and practical implications. On the theoretical side, the study contributes to the development of new frameworks for healthcare data management, leveraging blockchain technology to improve security, privacy, and interoperability. Second, this research helps in advancing understanding of blockchain's potential in healthcare, including its ability to provide secure, transparent, and tamper-proof record-keeping. On the practical side, the results have implications for improving patient care, enabling healthcare providers to access accurate and up-to-date patient information, and reducing errors and misdiagnoses. The findings also highlight the potential of blockchain to enhance data security in healthcare, reducing the risk of data breaches and cyber-attacks. One can also find suggestions that blockchain can increase efficiency in healthcare data management, reducing administrative burdens and costs associated with data exchange and management. Overall, the paper provides a comprehensive analysis of the theoretical and practical implications of blockchain in healthcare, offering valuable insights for researchers, practitioners, and policymakers.

Conclusion

Blockchain has emerged as a disruptive and enabling technology to address the issues related to current healthcare data management systems. Exploiting its decentralized, secure and tamper-proof characteristics, blockchain will have a great impact on data security, patient privacy and interoperability. Using cryptographic algorithms and consensus mechanisms, blockchain secures patient information so it cannot easily be accessed or altered without permission. It also empowers patients, allowing them to be in control of their data, and increases privacy while complying with standards of law like HIPAA and GDPR. The transparency in the system lets validated users to conduct real-time checks on the data integrity, something that could further build up the trust of the patients on the healthcare providers.

The research suggests that allowing medical centers to interoperate is one of the greatest promises for blockchain. Legacy healthcare providers faced many of the same barriers to data sharing that come from each institution maintaining their data in separate siloes. Blockchain can help solve that by

allowing a standard platform for secure real-time data sharing. This in effect can decrease the time it takes for a diagnosis and treatment, eliminate unnecessary tests and guarantee more efficient patient care. Smart contracts are also vital for enabling the automation of the data exchange process and the query for patient data with pre-agreed secure boundaries. This preserves the integrity of the data and reduces the administrative burden and thus the overall efficiency of health systems.

Despite such substantial benefits, there are several challenges to be addressed in the widespread acceptance of blockchain technology in healthcare. Regulatory hurdles are central, since to be used, blockchain will have to comply with multiple data privacy and health laws. The more data is placed on the blockchain (even in a private one), the more this problem will grow." Due to the distributed nature of blockchain, there is a tension between data sovereignty and the necessity to follow national or regional data protection laws. For example, GDPR's "right to be forgotten" clashes with blockchain's immutability – once data is added to the blockchain, it cannot be simply deleted (Narayan, 2019). This creates a legal challenge to be addressed and blockchain might need to be reconsidered and modified to comply with the regulations.

Technological challenges are also involved, especially in connecting blockchain with already existing legacy healthcare systems. A significant number of healthcare organizations are still using antiquated, non-interoperable systems, which are not capable of supporting the complex technical architecture behind the blockchain. The adaptation to a blockchain system entails significant up-front costs for technology, training, and infrastructure that is not an option for many institutions Mettler, 2016). Moreover, the scalability of blockchain systems, in particular for high-throughput domains such as healthcare, is a considerable challenge. These impediments, including transaction speed and energy consumption in public blockchain networks, needs to be overcome to make blockchain feasible for healthcare applications at scale (Zohar et al., 2021).

Another limitation is that of collaboration. Blockchain adoption in the healthcare sector comes with working with numerous institutions, including hospitals, insurers, pharmaceutical companies, regulators and patients. It might be impossible to meet all unique demands and expectations from institutions with different preoccupations and priorities. To succeed, political relationships will play a crucial role in standardizing data formats, privacy protocols, and designing the existing workflows. These relationships may be strained by prevalent organizational structures, aversion to changes and level of integration into the blockchain sector. However, it is evident that the impact can be achieved. Blockchain's potential revolutionary transformation on the mere process of healthcare information management, when executed

appropriately and put into use in view of progressive systems and compliance, can be primarily transformative when it becomes realized. Some of these limitations will likely be addressed by second-generation blockchain, which comes with improved scalability, consensus and develop the necessary interoperable standards. Secondly, a larger existence of blockchain will give healthcare providers access to an environment where the system will encourage the cost-effective management of patient data through its creation and security. It will improve patient care, processes, create immense savings and efficiency.

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