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Research Article

Harnessing Blockchain Technology in Healthcare: A Review of Applications and Interoperability

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ABSTRACT

Using blockchain technology in the healthcare sector provides solutions to persistent problems related to data security, interoperability, and cost-effectiveness. This meta-analysis of 126 peer-reviewed articles was conducted to assess the impact of blockchain on healthcare services. The articles selected for this meta-analysis were retrieved from academic databases, including PubMed, Scopus, and Lens.org. Only articles published between 2018 and 2023 were included in the analysis. This study yielded positive findings, including cost-effective data management, improved patient outcomes, operational efficiency, and enhanced service quality. It was also revealed that blockchain helps secure healthcare records through immutable data integrity, decentralized authentication, and reliable access control. Regarding security and privacy in healthcare systems, blockchain technology has strengthened security measures, enhanced privacy controls, and significantly reduced the risk of unauthorized data access. However, its implementation faces challenges, including interoperability issues due to a lack of standardization, variability in data formats across different organizations, incompatibility with legacy systems, scalability concerns, and additional complexities related to regulatory compliance. Blockchain applications in healthcare include implementing interoperability standards, utilizing smart contracts for data transformation, deploying middleware solutions for seamless integration, employing sharding techniques for enhanced scalability, and establishing blockchain-based compliance protocols. This study highlights the transformational opportunities that blockchain technology presents to the healthcare ecosystem, contributing to a roadmap for future research and policy development.

1. INTRODUCTION

At an age when data confidentiality, integrity, and availability are critical, blockchain technology is revolutionizing healthcare data management, patient care, and the healthcare environment (Bell et al., 2018). In fact, interest in blockchain within healthcare has grown considerably since 2018, driven by its intrinsic properties such as transparency, immutability, and decentralization, which collectively address critical healthcare challenges, including security, privacy, and data integrity (El-Gazzar & Stendal, 2020; Khot & Madalgi, 2023). The increasing adoption of blockchain in healthcare has led to innovative applications and initiatives to enhance trust and operational efficiency (Hasselgren et al., 2020).

The core attributes of blockchain (i.e., security, privacy, confidentiality, and decentralization) render it particularly suited to healthcare applications. Kumar (2021) notes that blockchain enables a decentralized, distributed environment, eliminating the need for a centralized authority and enhancing trust through cryptographic security measures. Despite these potential benefits, healthcare organizations face significant challenges in managing electronic health records (EHRs), including persistent data security threats, privacy concerns, and interoperability issues. Traditional centralized healthcare infrastructures are frequently hindered by security vulnerabilities, a lack of standardized data sharing, and inefficient resource allocation, thereby undermining the delivery of high-quality patient care (Kombe, 2020).

However, blockchain remains a subject of academic debate concerning its effectiveness and applicability. Indeed, although blockchains offer security enhancements and decentralization, many scholars remain skeptical of their adoption due to the complexities they introduce and potential drawbacks that could outweigh their benefits (Cirstea et al., 2018; El-Gazzar & Stendal, 2020). It is therefore important to accurately assess the potential of blockchain in healthcare and to establish measurable outcomes to bridge these different views.

Blockchain's potential to establish trust without intermediaries positions it as a viable solution to these longstanding healthcare challenges. By creating a secure, decentralized ledger for health data, blockchain enables secure storage, controlled sharing, and seamless interoperability among healthcare providers, researchers, and patients (Islam et al., 2023; Kim et al., 2021). Furthermore, Haleem et al. (2021) highlight blockchain's role in improving healthcare data analytics, enhancing institutional insight, and informed decision-making.

There has been growing interest in applying blockchain technology to healthcare, as evidenced by academic research and broader discussions (Ghosh et al., 2023). This increased attention, coupled with a rising number of related studies, underscores the need to review the existing research in this area. This trend is reflected in the growing number of review studies exploring the use of blockchain in healthcare, as seen in Figure 1. In fact, the global research community has published over 1,000 such studies in this field since 2000, according to analytics from TheLens.org.

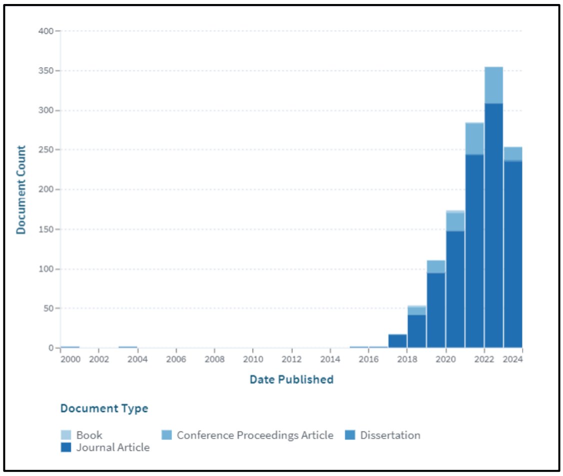

Figure 1. Trend of blockchain-related studies over time.

Given the growing interest and rapid developments in blockchain applications within healthcare, a systematic and critical evaluation of the current landscape is necessary (Kumar, 2021; Hasselgren et al., 2020). This meta-analysis systematically reviews existing literature to understand how blockchain technology impacts healthcare outcomes, security, privacy, interoperability, and cost-effectiveness. By addressing these critical research gaps, the study will explore the following specific questions:

1. What measurable impacts has blockchain technology had on the efficiency, cost-effectiveness, and overall quality of healthcare services?
2. How has the adoption of blockchain technology influenced the security and privacy of electronic health records?
3. What are the primary challenges and viable solutions for achieving effective data interoperability among healthcare organizations using blockchain?

By synthesizing findings from diverse studies, this meta-analysis offers a comprehensive perspective on blockchain's current state and practical implications in healthcare. Ultimately, the insights gained will identify trends, clarify existing knowledge gaps, and suggest future research and implementation pathways.

2. METHODOLOGY

This meta-analysis employed a comprehensive approach to assess recent blockchain applications within the healthcare sector. Initial steps included an extensive search of scholarly works from academic databases and resources, including PubMed, Scopus, The Lens, and Web of Science. To achieve this goal, various approaches were utilized, including data search strategy, individual study selection, data extraction, quality assessment, thematic analysis, data synthesis, ethical considerations, and data management and reporting.

Adopting the meta-analysis protocol of Reynoso et al. (2023), this study's procedure was divided into the following phases: Planning, Searching, Filtering, Synthesizing, and Reporting. The adopted protocol is illustrated in Figure 2. This structured approach ensured methodological rigor and consistency throughout the research process

Figure 2. Research Protocol.

2.1 Planning

By first assessing whether the study is needed, providing further analyses of the types of literature the study is expected to address, and then formulating research questions, this assessment is already underway to ensure the study is needed. The study focuses on the urgent need to analyze the effects of the broader healthcare landscape, especially on the application of blockchain in this sector. This emphasizes that literature will be included in the meta-analysis of the results of applying blockchain to the healthcare systems of the involved countries. This phase has two main activities: identifying the need for a review and formulating the research questions, as shown in Figure 2. The researchers discussed the impetus for conducting the review, as stated in the introductory section, and expanded on it in the related studies section.

2.2 Searching

The search process aims to extract and accumulate relevant studies and literature. This study used academic databases including PubMed, Scopus, Web of Science, and Lens.org. Using the established databases, the following keywords were used in the search: Blockchain, Southeast Asia, Health Sector, Emerging Trends, and Meta-Analysis. These keywords served as the primary search terms to locate relevant studies on blockchain in healthcare. The search strategy was meticulously designed, utilizing specific keywords and Boolean operators to identify pertinent studies. In line with the study's objectives, inclusion and exclusion criteria were rigorously applied during the initial screening of titles and abstracts. The selected studies were subjected to detailed data extraction, encompassing publication details, study design, characteristics of the blockchain applications, and relevant outcome measures.

2.3 Filtering

After searching, the data is filtered for selection. Initially, a year-based filter is applied to prioritize recent information and reduce irrelevant data. Additional criteria are then used to further refine the literature selection, aiming to include at least 50 coherent studies to support the primary analysis. The two-step filtering process, shown in Figure 3, involves initial screening based on publication year, followed by relevance refinement. The outcome is a carefully curated list of papers meeting the researcher's inclusion and exclusion criteria, ensuring accuracy and validity in the final analysis.

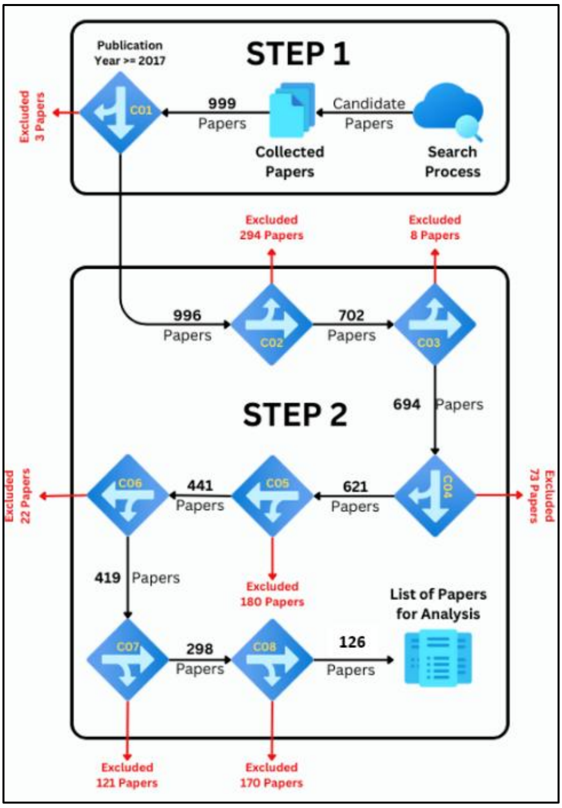

Figure 3. The Filtering Process.

The first step is eliminating redundant and irrelevant research by applying the specified criteria in Table 1. During the search, 999 studies were collected, with eight criteria developed. Focusing on the first criterion (C01), three papers published before 2018 were removed from the dataset, retaining 996 papers. The decision to include only studies published from 2018 onward was based on the rapid advancements in blockchain technology and its more substantial integration into healthcare systems starting that year. This period also marks an inflection point in global research interest, as trends in blockchain healthcare publications indicate. Applying the remaining inclusion and exclusion criteria, only 126 papers were retained for analysis.

The selected studies were subjected to detailed data extraction, encompassing publication details, study design, characteristics of the blockchain applications, and relevant outcome measures. Quality assessments were conducted according to established guidelines to evaluate the risk of bias in the included studies. Quantitative synthesis used appropriate statistical techniques to derive meaningful insights from the collective data. Sensitivity analyses were also considered to assess the robustness of findings, where applicable.

As part of the filtering process, criteria are included for inclusion and exclusion. These kinds of data allow further refinement of the filtering process and further narrowing of the literature. Table 1 outlines all the data needed for the filtering process, including inclusion and exclusion data.

Table 1. Inclusion and Exclusion Criteria.

ID	Inclusion Criteria	Exclusion Criteria
CO1	Papers that were published on or after 2018	Papers that were published before 2018
CO2	Papers about the health sector	Papers not about the health sector
CO3	Papers that are written in English	Papers that are not written in English
CO4	Studies reporting on the use of blockchain technology or distributed ledger technology in the health sector	Studies that do not pertain to blockchain or distributed ledger technology in the healthcare sector
CO5	Peer-reviewed sources, including academic journals, research papers, conference proceedings, theses and dissertations, or research articles	Non-peer-reviewed sources, including books, literature reviews, editorials, opinion pieces, or commentaries
CO6	Studies encompassing various aspects of healthcare, including but not limited to: Electronic Health Records Management, Medical data security and privacy, Supply chain management in Healthcare, Telemedicine and remote patient monitoring, Healthcare payment systems, Health research data management	Studies with inadequate or unclear information, insufficient methodological rigor, or incomplete data that prevent proper analysis and duplicate publications; if the same study is published in more than one source, only one instance will be included.
CO7	Studies with developmental aspects	Studies that fall short in addressing developmental aspects
CO8	Papers with Abstracts	Papers that do not have Abstracts

Table 2 shows the distribution of studies in the final dataset. The distribution of primary studies from 2018 to 2023 shows a significant upward trend in academic interest and research activity in blockchain applications in healthcare. Starting with only 2.4% of studies published in 2018, the percentage steadily increased each year, culminating in 39.7% of total studies published in 2023. This sharp rise underscores blockchain technology's growing relevance and perceived potential in addressing healthcare challenges, particularly in recent years.

The escalation in research output suggests heightened global recognition of blockchain's role in improving healthcare systems, driven by technological advancements, increased pilot implementations, and emerging needs for secure, interoperable, and efficient health data management. This trend also validates the decision to focus on studies from 2018 onward, a period when scholarly exploration of this topic gained meaningful traction.

Table 2. Distribution of Primary Studies Per Year

Year	Count (%)
2018	3 (2.4%)
2019	8 (6.3%)
2020	12 (9.5%)
2021	23 (18.3%)
2022	30 (23.8%)
2023	50 (39.7%)
TOTAL	126 00%)

2.4 Synthesis

In the subsequent stages of the research process, the selected studies undergo a rigorous examination to address the specified research questions. The analytical framework involves meticulously evaluating each study's findings, focusing on key healthcare parameters related to blockchain technology. For RQ1, the researchers scrutinized the studies to identify the tangible impacts of blockchain technology on the efficiency, cost-effectiveness, and overall quality of healthcare services. RQ2 delves into the security and privacy of EHRs. The adoption of blockchain technology is investigated to determine its effects on strengthening security and preserving the privacy of EHRs within healthcare systems. The researchers systematically reviewed relevant studies to extract insights into the implications and enhancements of blockchain technology in this crucial aspect of healthcare information management. Turning attention to RQ3, the focus shifts to understanding the intricacies of data interoperability among diverse healthcare organizations facilitated by blockchain technology. Each study is meticulously examined to identify key challenges and innovative solutions encountered in the pursuit of seamless data exchange within the healthcare ecosystem.

Studies were categorized according to predefined criteria to ensure methodological rigor and to incorporate only relevant and reliable information into the analysis. This iterative process of categorization and analysis is diligently repeated for each study until a comprehensive understanding of the subject matter is achieved, encompassing all facets of the established research questions.

Quantitative synthesis techniques were applied where applicable, including descriptive statistics to identify trends across the selected studies. Although many of the findings were qualitative, efforts were made to group outcomes by thematic relevance and frequency of reporting. Heterogeneity tests and effect size estimations were employed in cases with comparable quantitative data. This hybrid approach allowed for narrative and statistical aggregation, facilitating a deeper understanding of blockchain's impact on healthcare outcomes.

3. RESULTS AND DISCUSSION

The comprehensive meta-analysis conducted in this study affirms a growing body of evidence supporting blockchain's transformative potential to enhance healthcare service delivery. Drawing from 126 peer-reviewed sources published between 2018 and 2023, the analysis aimed to quantify the tangible impacts of blockchain on healthcare efficiency, cost-effectiveness, and quality (Loizou et al., 2019).

3.1 Measurable Impact of Blockchain on Healthcare Quality and Efficiency

Efficiency gains emerged as a consistent theme across the literature. Studies highlight blockchain's capacity to streamline workflows, eliminate intermediaries, and reduce administrative burdens traditionally associated with centralized systems (Chakraborty et al., 2019). These benefits are particularly valuable in high-friction processes such as claims management, data reconciliation, and medical supply chain coordination. Blockchain's transparent, decentralized architecture enables real-time data exchange, reducing redundancies and delays that often hinder clinical and administrative decision-making. As healthcare systems grapple with increasing patient loads, staffing shortages, and resource constraints, blockchain presents a scalable infrastructure to enhance systemic responsiveness, agility, and operational throughput.

In terms of cost-effectiveness, multiple studies underscore the financial viability of blockchain implementation. Mahammad and Kumar (2023) and Loizou et al. (2019) provide evidence of reduced overhead costs, fewer billing errors, and decreased exposure to fraud, enabled by blockchain's tamper-resistant records and automation capabilities. These cost savings extend beyond organizational finances—they can also lower patients' healthcare costs, making services more accessible and equitable. Blockchain optimizes human and technological resources by promoting automation, data accuracy, and trust in digital processes.

Equally compelling is blockchain’s contribution to improving the quality of healthcare services. Enhanced data sharing capabilities lead to more timely and accurate diagnostic decisions, better continuity of care, and improved patient monitoring (Cerchione et al., 2023; Lima et al., 2021). Real-time interoperability across systems allows healthcare professionals to access critical patient information without delay, minimizing clinical errors and improving treatment outcomes. Kombe (2020) further highlights blockchain’s role in supporting patient-centric care models by improving care coordination and enabling transparent data governance.

The findings indicate that blockchain is not merely a backend tool for administrative optimization but a core enabler of value-based healthcare. Its application touches multiple dimensions (i.e., operational, financial, and clinical), positioning it as a holistic solution to some of the sector's most persistent challenges. However, these benefits are maximized with proper system integration, stakeholder training, and supportive policy environments. As such, future research and pilot implementations should focus on refining these integration models to ensure scalability, sustainability, and real-world impact.

3.2 Impacts on the Security and Privacy of EHRs

This study analyzed how blockchain technology enhances the security and privacy of EHRs in healthcare systems to answer RQ2. The primary results indicate that blockchain has built a robust infrastructure to address the longstanding imperfection of traditional centralized data venues.

Immutability is one of the most important features of blockchain technology, meaning that once information is uploaded to the blockchain, it cannot be changed or deleted. The immutability of information is a compelling means of deterring unauthorized modifications, tampering, and fraud (Islam et al., 2023). As a result, health records hosted on blockchain networks are automatically immune to internal tampering and outside hacking. Moreover, decentralized authentication protocols decrease dependence on a centralized access point, reducing the risk of a single point of failure, one of the principal vulnerabilities in traditional EHR systems (Baseer et al., 2023). This, in turn, shifts the security perimeter and edge policy, thereby making the system more resilient.

In addition to improving data integrity and access security, blockchain empowers patients via privacy-preserving patient-controlled data sharing. Studies by Alzahrani et al. (2020), which are very concerned with who should access or edit their health data, show how blockchain can enforce micro-level access permissions. This patient-centered model enhances trust, promotes transparency, and aligns with global privacy regulations, including HIPAA and GDPR. As Mahmud (2018) points out, this type of data sovereignty cultivates an ethical, accountable data ecosystem in which health information stewardship is co-managed by patients and providers.

Strong access control policies and cryptographic privacy measures also significantly reduce the chances of unauthorized access or data leaks. According to Galaba et al. (2023) and Mamun et al. (2022), advanced encryption and distributed ledger technologies have significantly reduced exposure to threats such as insider misuse, ransomware attacks, and third-party breaches. This blockchain architecture, therefore, signifies a transition away from conventional, reactive cybersecurity methods employed after security breaches to proactive, trust-based infrastructure within the system in which security is intrinsic to its fundamental design.

Together, these findings signal that blockchain is more than a digital security mechanism; it is a paradigm shift in how healthcare data is secured and governed. It is a paradigm shift from having users access services controlled by providers in centralized service centers, such as hospitals, toward a decentralized, patient- and population-empowered model. In the face of growing concerns about data breaches, digital trust, and regulatory compliance, a promising, scalable solution is blockchain, which further improves health information systems by enhancing technical security and ethical accountability.

3.3 Key Challenges and Solutions in Achieving Data Interoperability

In response to RQ3, the study identified key barriers and potential approaches to leveraging blockchain technology to achieve effective data interoperability among healthcare stakeholders. Interoperability is critical to facilitating the secure exchange of health information that is interpretable and usable across platforms and institutions. Even though blockchain's distributed architecture provides an excellent foundation for interoperability, several technological, infrastructural, and regulatory obstacles persist that hinder its full potential.

Key Challenges: One of the biggest blockers to interoperability is the lack of an industry standard. While blockchain is built to enable the efficient and secure sharing of data in a decentralized manner, the lack of universal protocols makes cross-system interaction challenging. Without universally accepted frameworks for data exchange, many healthcare institutions still work in silos even when using blockchain networks (Cirstea et al., 2018). This disconnect erodes one of blockchain's fundamental promises: transparent, unified, and continuous access to patient data across disparate systems.

In addition, the diversity of data formats across healthcare providers adds layers of difficulty to the integration efforts. Health data are commonly captured in various formats, structures, and terminologies, particularly when addressing cross-border institutions or organizations that use legacy systems (Mahammad & Kumar, 2023; Kombe, 2020). Although these systems view the same data at the interface level, they represent it differently at the data structure level. The resulting non-interoperability prevents varied systems from interpreting and using each other's records, making real-time sharing impractical.

Moreover, legacy system integration adds complexity when integrating blockchain technology into healthcare systems. Most healthcare providers still use legacy infrastructure that cannot quickly employ blockchain-based solutions or adapt to the ever-evolving digital landscape. Upgrading these systems to interface with decentralized architectures is costly, technically challenging, and difficult to implement for most resource-constrained institutions.

Furthermore, high scalability concerns hinder the widespread application of blockchain technology in the healthcare sector. Healthcare data is multiplying exponentially, and maintaining the performance, speed, and efficiency of blockchain systems is challenging. This necessitates efficient strategies and protocols for processing transactions collectively, as large-scale implementations can lead to bottlenecks in transaction throughput, slower execution times, higher costs, and greater storage requirements (Kumar, 2021; Mahammad & Kumar, 2023).

Key Solutions: Despite these challenges, the literature has highlighted several promising solutions that can facilitate more effective blockchain-based interoperability in healthcare. Among these solutions, the drafting and implementation of interoperability standards are considered foundational. Common communication standards can also help systems across the board interpret, share, and process data more uniformly. Chakraborty et al. (2019) describe common data frameworks and vocabularies that can cross organizational and technical domains as critical. In addition, smart contracts for data transformation could provide an automated, scalable mechanism for transforming disparate data into a single, homogeneous view. These self-executing contracts can verify and transform heterogeneous data formats into uniform structures at the exchange point, reducing intervention and lowering interpretation errors (Mahammad & Kumar, 2023).

Middleware Solutions are the pivotal go-betweens connecting blockchain platforms and traditional health information networks. Middleware facilitates this compatibility by translating legacy data models into formats compatible with the blockchain, enabling systems already in use to connect to it without upending their entire infrastructure. Sharding techniques were introduced to solve scalability problems. Sharding enhances transaction throughput and makes the system more responsive to growing data loads by dividing the blockchain into smaller, parallel-processing segments. This innovation is of specific concern in healthcare, where high volume, latency, and performance are significant considerations.

Finally, blockchain-based compliance protocols, such as automated consent management and encrypted audit trails, can ensure that blockchain applications comply with privacy and data protection legislation. In this context, Kim et al. (2021) highlight the potential of embedded compliance features built directly into the blockchain, which could promote accountability for decentralized systems while alleviating regulatory compliance burdens on reporting entities.

4. CONCLUSION

This meta-analysis systematically reviewed the literature regarding blockchain technology in the healthcare sector, including 126 peer-reviewed studies published from 2018 to 2023. The results reaffirm that blockchain technology has the potential to revolutionize the delivery of healthcare services and improve efficiency, data security and privacy, and interoperability. Through automation of workflows, reduction of administrative overhead, and enabling secure, real-time data exchange, the analysis provides further evidence supporting the proposition that blockchain is a distinct technology with specific capabilities that drive significant improvement in operational performance, cost-effectiveness, and the overall quality of care delivery relevant to the study's research questions.

From a security and privacy perspective, the research reinforces blockchain as a next-generation infrastructure for managing EHRs. With features such as immutable ledgers, decentralized authentication, and patient-controlled access, blockchain is poised to address the longstanding challenges of traditional data systems. This reduces the risk of data breaches and unauthorized access and facilitates compliance with privacy regulations worldwide, including HIPAA and GDPR, thereby promoting greater transparency and trust in digital healthcare settings.

Nevertheless, this promise of blockchain in healthcare comes with clear challenges; one area to focus on may be data interoperability. Full-scale implementations still face a significant hurdle, including a lack of standardized protocols, heterogeneous data formats, legacy infrastructure, and scalability constraints. Despite these issues, this paper identifies feasible ways to mitigate their adverse effects, including the use of interoperability standards, smart contracts, middleware systems, and blockchain-native compliance protocols. These approaches lay the foundation for scalable, secure, and interoperable healthcare ecosystems.

The findings of this study make important contributions to both practical and policy applications. For examiners, blockchain provides additional insight into advanced care delivery models and the time and planning structures required to harness the value of value-based care. For policymakers and regulators, the findings argue for creating enabling frameworks that standardize blockchain adoption while still protecting legal and ethical guidelines. Moreover, the growing path of academic research and implementation pilots indicates robust momentum for future innovation in this space.

Going forward, more empirical work is required to: (1) confirm blockchain's functionality within live healthcare environments; (2) establish the adoption behaviors of patients and providers concerning blockchain; and (3) evaluate the long-term consequences on health outcomes. Robust monitoring and evaluation frameworks must accompany any pilot implementations to gather real-world evidence. Collaboration across academia, industry, and government will be essential to bringing blockchain's theoretical benefits to life and implementing lasting change in health care.

Ultimately, while no solution is perfect, Blockchain offers the potential to transform how healthcare data is handled, transmitted, and secured, potentially advancing a more effective, secure, and patient-centric healthcare system.

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DECLARATIONS

Conflict of Interest

The authors declare they have no conflict of interest.

Informed Consent

Not applicable. This study did not involve human participants; thus, informed consent was not required.

Ethics Approval

This study did not involve human or animal subjects; hence, ethics approval is unnecessary.

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