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Blockchain in healthcare: A comprehensive review of applications and security concerns

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Abstract

Blockchain technology presents a transformative opportunity for the healthcare industry, offering enhanced data security, integrity, transparency, and operational efficiency. This paper comprehensively examines blockchain's applications, advantages, limitations, and challenges in healthcare. Blockchain ensures the privacy of patient data while complying with regulations such as HIPAA and GDPR, and its immutability guarantees data integrity. Moreover, blockchain streamlines operations, reducing fraud and errors in billing and claims processing. Despite its potential, blockchain faces technical complexities, regulatory hurdles, and scalability issues. Interoperability between diverse healthcare systems remains challenging, and energy consumption is a concern in some blockchain implementations. Addressing these challenges and fostering education and adoption are crucial steps toward realizing the full potential of blockchain in revolutionizing healthcare delivery.

Keywords: Blockchain; Healthcare; Data Security; Data Privacy; Interoperability; Smart Contracts

1. Introduction

Fundamentally, blockchain technology is a decentralized digital ledger that records transactions across many computers to ensure the data's security, transparency, and immutability. Conceptualized initially to underpin cryptocurrencies like Bitcoin, its unique attributes—decentralization, cryptographic security, and resistance to tampering—have made it applicable across various domains beyond finance (Komalavalli, Saxena, & Laroiya, 2020; Laroiya, Saxena, & Komalavalli, 2020; Namasudra, Deka, Johri, Hosseinpour, & Gandomi, 2021). At its core, a blockchain is a chain of blocks, each containing several transactions. Once a block is completed, it is linked to the previous block, forming a chain of blocks that show every transaction made in the history of that blockchain. This ensures not only the integrity of the data recorded but also its accessibility and verifiability by all participants in the network without the need for a central authority (Sharma & Balamurugan, 2020).

In healthcare, blockchain technology promises to revolutionize how medical records are stored, shared, and managed, addressing longstanding issues such as data fragmentation, security, and patient privacy (Attaran, 2022; Capece & Lorenzi, 2020; Yaqoob, Salah, Jayaraman, & Al-Hammadi, 2021). The immutable nature of blockchain makes it an ideal platform for maintaining a single, tamper-proof version of patient health records that authorized parties can securely

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access. This technology also offers solutions for enhancing the traceability of pharmaceuticals and medical supplies, ensuring authenticity and combating counterfeits. Additionally, blockchain can streamline administrative processes in healthcare, such as billing and claims management, by automating and securing transactions and reducing the potential for fraud (Laroiya et al., 2020; Mukherjee & Singh, 2020; Narikimilli, Kumar, Antu, & Xie, 2020).

This comprehensive review aims to explore the multifaceted applications of blockchain technology in healthcare and critically analyze the associated security concerns. By examining the current literature and emerging practices, this review aims to provide a holistic understanding of how blockchain can address some of the most pressing challenges in healthcare, including data privacy, security vulnerabilities, and the need for interoperability among diverse healthcare systems. Furthermore, it seeks to identify the limitations and potential challenges of integrating blockchain into healthcare ecosystems, offering insights into future research, development, and implementation directions.

This review covers a broad spectrum of blockchain applications in healthcare, from patient data management and supply chain integrity to insurance processes and beyond. It will delve into various blockchain models (e.g., public, private, consortium) and their suitability for different healthcare applications, considering the unique requirements of the healthcare sector regarding data sensitivity, regulatory compliance, and operational efficiency. While this approach allows for a comprehensive overview of the subject, the rapidly evolving nature of blockchain technology and its applications in healthcare means that new developments might emerge following the completion of this review. Additionally, the review will highlight, rather than resolve, ongoing debates about the best practices for blockchain implementation in healthcare, recognizing the need for further empirical research and regulatory guidance in this nascent field.

2. Background and Fundamentals of Blockchain Technology

Blockchain technology is a distributed ledger technology (DLT) that maintains records on a network of computers but without a central ledger or a single administrator. This innovative approach to record-keeping is built on several foundational principles.

Blockchain technology is characterized by decentralization, ensuring that it is not controlled by a single entity but distributed across a network of computers (nodes), each maintaining a copy of the ledger (Bhutta et al., 2021). This decentralized nature eliminates the vulnerability of a single point of failure, enhancing data integrity and security. Transparency and immutability are fundamental attributes of blockchain. Every transaction recorded on the blockchain is transparent and can be verified by all participants. Once a transaction is added to the blockchain, it becomes immutable, meaning it cannot be altered or deleted. This immutability guarantees the ledger's integrity, making it a trustworthy source of information (Bonnah & Shiguang, 2020; Komalavalli et al., 2020; Zeng et al., 2020).

Security is a core feature of blockchain technology, achieved through cryptographic hash functions. Each block in the blockchain contains a unique hash of the previous block, creating a secure and tamper-resistant link between blocks. Coupled with consensus mechanisms, such as proof-of-work or proof-of-stake, blockchain ensures the validation and security of transactions, making it highly resistant to tampering and fraud. Smart contracts are self-executing contracts with predefined terms encoded directly into code. These contracts automatically enforce and execute the agreed-upon terms when specific conditions are met. Smart contracts facilitate trustless and automated transactions, reducing the need for intermediaries and enhancing the efficiency and security of agreements within the blockchain ecosystem (Abed, Jaffal, Mohd, & Al-Shayeji, 2021; Kuznetsov et al., 2021).

2.1. Evolution of Blockchain and Its Adoption in Healthcare

The evolution of blockchain technology can be traced back to its inception with the creation of Bitcoin in 2009 as a peer-to-peer electronic cash system. However, the potential applications of blockchain quickly expanded beyond cryptocurrencies. Developers and researchers began to explore how its properties could address challenges in various sectors, including healthcare.

In healthcare, blockchain's journey began with the promise of secure and interoperable electronic health records (EHRs) (Abed et al., 2021; Singh, Jabbar, Shandilya, Vovk, & Hnatiuk, 2023). The ability to create an immutable, universally accessible ledger of patient data presented a solution to issues of data fragmentation, security breaches, and patient privacy concerns. Over time, applications have expanded to include drug traceability, combatting counterfeit drugs, managing healthcare supply chains, and facilitating secure, transparent data sharing for research and clinical trials (Quasim, Radwan, Alshmrani, & Meraj, 2020; Stafford & Treiblmaier, 2020).

2.2. Types of Blockchain and Their Relevance to Healthcare

Blockchain networks can be categorized into three main types, each with distinct characteristics and implications for healthcare (Abu-Elezz, Hassan, Nazeemudeen, Househ, & Abd-Alrazaq, 2020; Chukwu & Garg, 2020; Hasselgren, Kralevska, Gligoroski, Pedersen, & Faxvaag, 2020):

- Public Blockchains: These are open networks where anyone can participate and contribute to the consensus process. Bitcoin and Ethereum are prime examples. In healthcare, public blockchains offer the highest level of transparency but raise concerns regarding privacy and scalability due to their open nature.
- Private Blockchains: Operated by a single organization, private blockchains control who can participate in the network. This type is more scalable and offers greater privacy than public blockchains, making it suitable for managing sensitive health data where access needs to be restricted to authorized entities.
- Consortium Blockchains: These are semi-decentralized and governed by a group of organizations rather than a single entity. Consortium blockchains balance the openness of public blockchains and the control of private ones. They are particularly relevant for collaborative healthcare projects involving multiple stakeholders, such as hospitals, research institutions, and insurance companies, where shared governance is beneficial (Llamas Covarrubias & Llamas Covarrubias, 2021).

Each type of blockchain holds different implications for healthcare applications. Public blockchains offer unparalleled transparency and security, making them ideal for pharmaceutical supply chain management. Private blockchains provide the privacy and control necessary for managing patient records and sensitive health data. Consortium blockchains are well-suited for collaborative healthcare endeavours, enabling secure and efficient data sharing across different organizations while maintaining oversight and privacy.

The choice of blockchain type depends on the specific healthcare application, regulatory requirements, and the need for privacy, scalability, and interoperability. As the healthcare sector continues to evolve, the adoption of blockchain technology presents an opportunity to address longstanding challenges, paving the way for more secure, efficient, and patient-centred healthcare systems.

3. Applications of Blockchain in Healthcare

3.1. Patient Data Management

Blockchain technology offers a transformative approach to managing patient data, addressing critical security, data integrity, and interoperability issues. By leveraging blockchain, healthcare providers can create a decentralized and immutable patient data record, ensuring that medical records are secure, tamper-proof, and accessible only by authorized parties. This technology facilitates the creation of a unified patient health record that can be updated in real time, providing a comprehensive view of a patient's medical history across different healthcare providers and institutions (Attaran, 2022; Yeung, 2021).

Interoperability, a long-standing challenge in healthcare, is significantly enhanced through blockchain. It enables disparate healthcare systems and applications to securely share and access patient data, improving care coordination and outcomes. Moreover, blockchain's cryptographic protection ensures patient privacy and compliance with regulations like HIPAA (Health Insurance Portability and Accountability Act) by allowing patients to control who can access their medical information, enhancing trust and security in managing health data (Aljaloud & Razzaq, 2023; Awasthi, Bhattacharjee, & Karande, 2023; Taherdoost, 2023).

3.2. Supply Chain Management

The pharmaceutical supply chain is fraught with challenges, including counterfeit drugs, lack of transparency, and inefficiencies. Blockchain technology addresses these issues by providing a secure and transparent platform for tracking pharmaceuticals and medical supplies production, distribution, and sale. Each transaction in the supply chain—from manufacturing to delivery to the end consumer—is recorded on the blockchain, creating an immutable history of the product's journey.

This traceability ensures that stakeholders can verify the authenticity of pharmaceuticals, reducing the risk of counterfeit drugs entering the market. Furthermore, blockchain can improve the efficiency of the supply chain by automating processes and reducing the need for intermediaries, thereby lowering costs and improving access to essential medicines (Uddin, 2021).

3.3. Clinical Trials and Research

Blockchain can significantly enhance the integrity, transparency, and efficiency of clinical trials and research. By securely recording all trial data on a blockchain, researchers can ensure that data is not altered or tampered with, maintaining the integrity of the research results. This immutable data record helps build trust among participants, regulators, and the public.

Blockchain also streamlines patient consent management using smart contracts, which can automatically enforce consent agreements and ensure patients' data is used following their preferences. Additionally, blockchain facilitates transparent reporting of trial results, making sharing data with regulatory bodies, participants, and the wider scientific community easier, thereby advancing medical research and innovation (Hang, Kim, Kim, & Kim, 2021; Omar, Jayaraman, Salah, Yaqoob, & Ellahham, 2021).

3.4. Insurance and Billing Management

In the complex landscape of healthcare billing and insurance claims, blockchain offers solutions to streamline processes, reduce administrative costs, and minimize fraud. By automating billing and claims processing through smart contracts, blockchain can ensure that transactions are executed only when specific conditions are met, reducing errors and discrepancies.

This automation speeds up processing times and enhances transparency, as each transaction is recorded on the blockchain. This transparency reduces the potential for fraud as auditing and verifying transactions becomes easier. Additionally, blockchain can facilitate direct and secure communication between healthcare providers and insurers, further simplifying the billing and claims process (Ghode, Jain, Soni, Singh, & Yadav, 2020).

3.5. Telemedicine and Remote Monitoring

As telemedicine and remote monitoring of patients become increasingly prevalent, especially in the wake of global health crises, blockchain technology can play a crucial role in securing these digital healthcare services. Blockchain can safeguard the transmission of patient data collected from remote monitoring devices, ensuring that the data is secure, tamper-proof, and accessible only by authorized healthcare providers. This secure data exchange is crucial for maintaining patient privacy and trust in telemedicine services. Furthermore, blockchain enables the creation of secure, decentralized identities for patients, which can streamline access to telemedicine services and ensure that health data is accurately linked to the correct patient, enhancing the quality and safety of remote healthcare delivery (Abugabah, Nizamuddin, & Alzubi, 2020; Jabarulla & Lee, 2021).

4. Security Concerns in Blockchain for Healthcare

4.1. Data Privacy

One of the paramount concerns in adopting blockchain technology within healthcare is ensuring the privacy of patient data while complying with stringent regulatory standards such as the Health Insurance Portability and Accountability Act in the United States and the General Data Protection Regulation (GDPR) in the European Union. These regulations mandate the protection of sensitive patient information and the rights of individuals over their data. Blockchain's immutable and transparent nature poses unique challenges in this regard, as once data is recorded, it cannot be altered or deleted, potentially conflicting with the right to be forgotten stipulated by GDPR (Akanfe, Lawong, & Rao, 2024; Esmaeilzadeh, 2022).

To address these privacy concerns, healthcare blockchain applications often employ advanced cryptographic techniques such as zero-knowledge proofs or private or consortium blockchains where access is controlled and regulated. Nonetheless, ensuring that these solutions comply with legal requirements while maintaining the security and integrity of patient data remains a significant challenge.

4.2. Security Vulnerabilities

While blockchain is renowned for its security features, certain vulnerabilities can pose risks, particularly in healthcare applications involving sensitive data. For instance, a 51% attack, where a single entity gains control of more than half of the network's computing power, could theoretically alter transactions on a public blockchain. Although such attacks are more feasible against smaller, less secure networks, the potential implications for healthcare data integrity are serious. Smart contracts and automated agreements executed on the blockchain introduce another vulnerability vector. Bugs in smart contract code can be exploited to manipulate outcomes or access unauthorized data. Ensuring smart

contracts are secure and free of vulnerabilities is crucial, particularly when they are used to handle sensitive health information or automate critical healthcare processes (Han, Sui, Yu, Liu, & Chen, 2021; Saad et al., 2020).

4.3. Interoperability Issues and Scalability

Achieving interoperability among diverse blockchain systems and existing healthcare IT infrastructures is a significant challenge. Healthcare data is complex and heterogeneous, encompassing various formats and standards. Integrating blockchain solutions with legacy systems requires a level of standardization and compatibility that is difficult to achieve, given the nascent stage of blockchain interoperability solutions. These challenges can hinder the seamless exchange of data across different blockchain networks and traditional healthcare information systems, limiting the potential benefits of blockchain technology in healthcare (Jabbar, Fetais, Krichen, & Barkaoui, 2020; F. Reegu, Daud, & Alam, 2021; F. A. Reegu et al., 2022).

Scalability is a critical issue for blockchain networks, especially in healthcare applications that require processing vast amounts of data quickly and efficiently. Most blockchain architectures struggle to handle high transaction volumes without compromising performance or security. This limitation can impact healthcare applications that depend on real-time data access and processing, such as telemedicine and remote patient monitoring. Finding scalable blockchain solutions that can accommodate the growing data needs of the healthcare sector remains a significant technical challenge (Mazlan et al., 2020).

4.4. Regulatory and Legal Challenges

The implementation of blockchain in healthcare faces various legal and regulatory hurdles. The decentralized nature of blockchain complicates the application of existing regulatory frameworks, which are typically designed for centralized entities. Questions regarding jurisdiction, liability, and compliance accountability are yet to be fully addressed. Moreover, the rapid evolution of blockchain technology outpaces the development of specific legal standards and regulations, creating uncertainty for healthcare providers and blockchain developers. These regulatory challenges are compounded by the need for blockchain systems to comply with healthcare-specific regulations, which vary significantly across jurisdictions. Navigating this complex regulatory environment requires careful planning and collaboration with legal experts to ensure that blockchain healthcare applications are effective and compliant.

In conclusion, while blockchain technology offers promising solutions to many of the healthcare industry's challenges, significant security concerns must be addressed. Ensuring data privacy, mitigating security vulnerabilities, achieving interoperability, addressing scalability issues, and navigating the regulatory landscape are critical for successfully integrating blockchain into healthcare systems. As the technology matures and these challenges are discussed progressively, blockchain has the potential to significantly enhance the security, efficiency, and transparency of healthcare services.

5. Advantages of Blockchain in Healthcare

Integrating blockchain technology into healthcare systems offers many advantages, promising to address some of the sector's most persistent challenges. By leveraging blockchain, healthcare can benefit from enhanced data security and privacy, improved data integrity and transparency, increased operational efficiency, and reduced fraud and errors significantly.

Blockchain technology's inherent security features offer a robust solution to the healthcare industry's critical need for secure data handling and privacy. Through advanced cryptographic techniques, blockchain ensures patient data is encrypted and stored across a distributed network, making it virtually impervious to unauthorized access and cyber-attacks. This decentralized approach eliminates single points of failure, significantly reducing the risk of data breaches. Furthermore, blockchain enables fine-grained access controls, allowing patients more autonomy over their data. Patients can control who has access to their medical information, under what circumstances, and for how long, aligning with privacy regulations and enhancing trust in healthcare systems (Malamas, Kotzanikolaou, Dasaklis, & Burmester, 2020; Peng, Zhang, & Lin, 2023).

Blockchain technology ensures the integrity and transparency of medical data through its immutable ledger. Once information is recorded on a blockchain, it cannot be altered or deleted, ensuring that the medical records are accurate and tamper-proof. This immutability is crucial for clinical trials, patient records, and other sensitive medical data requiring high trust and verification. Transparency is achieved without compromising privacy, as blockchain networks can be designed to allow stakeholders to verify transactions and data authenticity without revealing sensitive

information. This aspect is particularly beneficial in pharmaceutical supply chains and clinical research, where stakeholders must verify data integrity and processes (Ahmad et al., 2021).

Blockchain can streamline numerous administrative and operational processes in healthcare, leading to increased efficiency and reduced costs. By automating routine tasks such as patient data entry, billing, and claims processing through smart contracts, healthcare providers can minimize manual errors and administrative overhead. This automation speeds up processes and reduces the time and resources spent on reconciling discrepancies and resolving disputes. Moreover, blockchain facilitates seamless data exchange between disparate healthcare systems and institutions, improving coordination and reducing delays in patient care. This interoperability is essential for achieving a more integrated and efficient healthcare ecosystem where information flows smoothly across providers, payers, and patients (Velmovitsky, Bublitz, Fadrique, & Morita, 2021).

Blockchain's transparency and auditability are crucial in reducing fraud and errors in the healthcare sector. The technology's ability to securely and accurately record transactions and data makes it an effective tool for combating billing fraud, insurance fraud, and counterfeit pharmaceuticals. Stakeholders can trace the origin, movement, and authenticity of drugs in the supply chain and verify the accuracy of billing and claims data. Additionally, using smart contracts can automate and enforce the execution of contracts and agreements, further reducing the potential for fraud and errors. This automation ensures that payments, claims, and other transactions are processed only when specific conditions are met, minimizing the risk of duplicate claims, incorrect billing, and unauthorized access to services.

6. Limitations and Challenges

While promising, the adoption of blockchain technology in healthcare is not without its limitations and challenges. These encompass technical complexities, regulatory hurdles, and issues related to adoption, scalability, energy consumption, and system complexity.

6.1. Technical Challenges

The technical challenges associated with implementing blockchain in healthcare are multifaceted. Firstly, the complexity of integration poses a significant hurdle. Integrating blockchain with existing healthcare IT systems and infrastructure is a complex endeavour, requiring meticulous planning and execution to ensure compatibility with diverse data formats, standards, and legacy systems. Secondly, achieving interoperability between blockchain networks and healthcare systems remains a formidable challenge. The healthcare data landscape is characterized by its heterogeneity and fragmentation, making it challenging to establish standardized interfaces and protocols that facilitate seamless data exchange. Lastly, ensuring the security of smart contracts is paramount. Vulnerabilities in smart contract code can lead to exploitation and financial losses. Continuous efforts are essential to enhance the auditing and testing of smart contracts, mitigating the risk of security breaches.

6.2. Regulatory and Legal Challenges

Navigating the regulatory landscape of blockchain in healthcare entails confronting multiple challenges. Firstly, regulatory uncertainty exists as the framework for blockchain technology continues to evolve. Current regulations may not sufficiently encompass the distinctive features and intricacies of blockchain, necessitating the involvement of legal expertise and close collaboration with regulatory authorities. Secondly, ensuring compliance with data privacy regulations such as HIPAA and GDPR remains a vital concern. Balancing blockchain's inherent transparency with the imperative to safeguard sensitive patient data is an ongoing dilemma, particularly concerning principles like the right to be forgotten and data access control. Lastly, establishing liability and accountability within blockchain networks can be intricate, particularly in data breaches or disputes. Therefore, creating comprehensive legal frameworks becomes imperative to foster patient trust and protect the interests of all stakeholders involved in healthcare blockchain initiatives.

6.3. Scalability, Energy Consumption, and Complexity

In the realm of scalability, energy dynamics, and intricate governance, the world of blockchain technology reveals its complexities. Scalability, a towering challenge, becomes especially evident in public blockchain networks. As transactions and participants surge, the ominous spectre of network congestion looms, causing the gears of transaction processing to grind slower. Yet, glimmers of hope emerge on the horizon in the form of innovative solutions like sharding and layer-2 scaling, offering promises of overcoming the scalability impasse.

Meanwhile, the ravenous energy appetite of proof-of-work (PoW) blockchains, typified by Bitcoin and Ethereum, sparks environmental concerns that echo far and wide. Sustainability beckons, and transitioning to more energy-efficient consensus mechanisms like proof-of-stake (PoS) tantalizes as a potential saviour. Amidst this complexity, governance takes centre stage, particularly in the consortium and decentralized networks, where consensus-driven decision-making processes, protocol upgrades, and adjustments test the mettle of network participants, leading to the deliberation that can be as slow as it is contentious. Amid these intricate machinations, the user experience emerges as a critical element. Blockchain interfaces and wallets, though powerful, can be arcane for non-technical users, beckoning the imperative of enhancing user-friendliness and crafting interfaces that beckon widespread adoption, a particularly vital quest in the healthcare realm, where user-friendliness is the cornerstone of success.

6.4. Adoption-Related Challenges

In the realm of adoption-related challenges, a vivid landscape of hurdles unfolds. Firstly, there is the formidable cost of implementation casting a shadow. The development and integration of blockchain solutions in healthcare can be a financially demanding endeavour. For smaller healthcare entities, these costs present substantial barriers, curtailing their access to the transformative advantages of blockchain technology. Secondly, the canvas is adorned with the need for education and training. Healthcare professionals and stakeholders find themselves in a landscape where they must traverse a learning curve to grasp the intricacies of blockchain technology and its myriad applications. Bridging this knowledge gap becomes a pivotal bridge to successful adoption, painting a portrait of enlightened healthcare practitioners. Lastly, resistance to change emerges as a formidable antagonist. Within the healthcare industry, where tradition often reigns, blockchain adoption faces the challenge of overcoming inertia and perceived risks. The canvas of innovation must illuminate a path forward, enticing healthcare professionals and organizations to embrace the potential of blockchain-based solutions.

7. Conclusion

In conclusion, blockchain technology holds immense promise for revolutionizing the healthcare industry. Its potential to enhance data security, privacy, integrity, and transparency, streamline healthcare operations, and reduce fraud is significant. However, the adoption of blockchain in healthcare is not without its challenges. Technical complexities, regulatory uncertainties, scalability, energy consumption, and system complexity issues must be carefully addressed. Interoperability between diverse healthcare systems and legacy infrastructure remains a critical concern, as does ensuring compliance with data privacy regulations.

Nonetheless, as blockchain technology matures and the healthcare industry continues to evolve, these challenges can be overcome through ongoing research, collaboration, and innovation. By addressing these limitations and harnessing the advantages of blockchain, the healthcare sector has the potential to create a more secure, efficient, and patient-centred ecosystem that benefits both providers and patients alike. The future of healthcare holds exciting possibilities as blockchain technology continues to shape the industry's landscape.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abed, S. e., Jaffal, R., Mohd, B. J., & Al-Shayeji, M. (2021). An analysis and evaluation of lightweight hash functions for blockchain-based IoT devices. Cluster Computing, 24, 3065-3084.

[2] Abu-Elezz, I., Hassan, A., Nazeemudeen, A., Househ, M., & Abd-Alrazaq, A. (2020). The benefits and threats of blockchain technology in healthcare: A scoping review. International Journal of Medical Informatics, 142, 104246.

[3] Abugabah, A., Nizamuddin, N., & Alzubi, A. A. (2020). Decentralized telemedicine framework for a smart healthcare ecosystem. Ieee Access, 8, 166575-166588.

[4] Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., Ellahham, S., & Omar, M. (2021). The role of blockchain technology in telehealth and telemedicine. International Journal of Medical Informatics, 148, 104399.

[5] Akanfe, O., Lawong, D., & Rao, H. R. (2024). Blockchain technology and privacy regulation: Reviewing frictions and synthesizing opportunities. International Journal of Information Management, 76, 102753.

[6] Aljaloud, A., & Razzaq, A. (2023). Modernizing the Legacy Healthcare System to Decentralize Platform Using Blockchain Technology. Technologies, 11(4), 84.

[7] Attaran, M. (2022). Blockchain technology in healthcare: Challenges and opportunities. International Journal of Healthcare Management, 15(1), 70-83.

[8] Awasthi, M. V., Bhattacharjee, S., & Karande, N. (2023). Convergence of Internet of Medical Things, Artificial Intelligence, and Blockchain in Healthcare: A Transformative Platform for Interoperable Healthcare. Convergence, 10(6).

[9] Bhutta, M. N. M., Khwaja, A. A., Nadeem, A., Ahmad, H. F., Khan, M. K., Hanif, M. A., . . . Cao, Y. (2021). A survey on blockchain technology: Evolution, architecture and security. Ieee Access, 9, 61048-61073.

[10] Bonnah, E., & Shiguang, J. (2020). DecChain: A decentralized security approach in Edge Computing based on Blockchain. Future Generation Computer Systems, 113, 363-379.

[11] Capece, G., & Lorenzi, F. (2020). Blockchain and Healthcare: Opportunities and Prospects for the EHR. sustainability, 12(22), 9693.

[12] Chukwu, E., & Garg, L. (2020). A systematic review of blockchain in healthcare: frameworks, prototypes, and implementations. Ieee Access, 8, 21196-21214.

[13] Esmaeilzadeh, P. (2022). Benefits and concerns associated with blockchain-based health information exchange (HIE): a qualitative study from physicians' perspectives. BMC Medical Informatics and Decision Making, 22(1), 80.

[14] Ghode, D. J., Jain, R., Soni, G., Singh, S. K., & Yadav, V. (2020). Architecture to enhance transparency in supply chain management using blockchain technology. Procedia Manufacturing, 51, 1614-1620.

[15] Han, R., Sui, Z., Yu, J., Liu, J., & Chen, S. (2021). Fact and fiction: Challenging the honest majority assumption of permissionless blockchains. Paper presented at the Proceedings of the 2021 ACM Asia Conference on Computer and Communications Security.

[16] Hang, L., Kim, B., Kim, K., & Kim, D. (2021). A permissioned blockchain-based clinical trial service platform to improve trial data transparency. BioMed research international, 2021.

[17] Hasselgren, A., Kralevska, K., Gligoroski, D., Pedersen, S. A., & Faxvaag, A. (2020). Blockchain in healthcare and health sciences—A scoping review. International Journal of Medical Informatics, 134, 104040.

[18] Jabarulla, M. Y., & Lee, H.-N. (2021). A blockchain and artificial intelligence-based, patient-centric healthcare system for combating the COVID-19 pandemic: Opportunities and applications. Paper presented at the Healthcare.

[19] Jabbar, R., Fetais, N., Krichen, M., & Barkaoui, K. (2020). Blockchain technology for healthcare: Enhancing shared electronic health record interoperability and integrity. Paper presented at the 2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT).

[20] Komalavalli, C., Saxena, D., & Laroiya, C. (2020). Overview of blockchain technology concepts. In Handbook of research on blockchain technology (pp. 349-371): Elsevier.

[21] Kuznetsov, A., Oleshko, I., Tymchenko, V., Lisitsky, K., Rodinko, M., & Kolhatin, A. (2021). Performance analysis of cryptographic hash functions suitable for use in blockchain. International Journal of Computer Network & Information Security, 13(2), 1-15.

[22] Laroiya, C., Saxena, D., & Komalavalli, C. (2020). Applications of blockchain technology. In Handbook of research on blockchain technology (pp. 213-243): Elsevier.

[23] Llamas Covarrubias, J. Z., & Llamas Covarrubias, I. N. (2021). Different types of government and governance in the blockchain. Journal of Governance and Regulation, 10(1).

[24] Malamas, V., Kotzanikolaou, P., Dasaklis, T. K., & Burmester, M. (2020). A hierarchical multi blockchain for fine grained access to medical data. Ieee Access, 8, 134393-134412.

[25] Mazlan, A. A., Daud, S. M., Sam, S. M., Abas, H., Rasid, S. Z. A., & Yusof, M. F. (2020). Scalability challenges in healthcare blockchain system—a systematic review. Ieee Access, 8, 23663-23673.

[26] Mukherjee, P., & Singh, D. (2020). The opportunities of blockchain in health 4.0. Blockchain Technology for Industry 4.0: Secure, Decentralized, Distributed and Trusted Industry Environment, 149-164.

[27] Namasudra, S., Deka, G. C., Johri, P., Hosseinpour, M., & Gandomi, A. H. (2021). The revolution of blockchain: State-of-the-art and research challenges. Archives of Computational Methods in Engineering, 28, 1497-1515.

[28] Narikimilli, N. R. S., Kumar, A., Antu, A. D., & Xie, B. (2020). Blockchain applications in healthcare–a review and future perspective. Paper presented at the Blockchain–ICBC 2020: Third International Conference, Held as Part of the Services Conference Federation, SCF 2020, Honolulu, HI, USA, September 18-20, 2020, Proceedings 3.

[29] Omar, I. A., Jayaraman, R., Salah, K., Yaqoob, I., & Ellahham, S. (2021). Applications of blockchain technology in clinical trials: review and open challenges. Arabian Journal for Science and Engineering, 46, 3001-3015.

[30] Peng, G., Zhang, A., & Lin, X. (2023). Patient-centric fine-grained access control for electronic medical record sharing with security via dual-blockchain. IEEE Transactions on Network Science and Engineering.

[31] Quasim, M. T., Radwan, A. A. E., Alshmrani, G. M. M., & Meraj, M. (2020). A blockchain framework for secure electronic health records in healthcare industry. Paper presented at the 2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE).

[32] Reegu, F., Daud, S. M., & Alam, S. (2021). Interoperability challenges in healthcare blockchain system-A systematic review. Annals of the Romanian Society for Cell Biology, 15487-15499.

[33] Reegu, F. A., Abas, H., Jabbari, A., Akmam, R., Uddin, M., Wu, C.-M., . . . Khalaf, O. I. (2022). Interoperability requirements for blockchain-enabled electronic health records in healthcare: A systematic review and open research challenges. Security and Communication Networks, 2022.

[34] Saad, M., Spaulding, J., Njilla, L., Kamhoua, C., Shetty, S., Nyang, D., & Mohaisen, D. (2020). Exploring the attack surface of blockchain: A comprehensive survey. IEEE Communications Surveys & Tutorials, 22(3), 1977-2008.

[35] Sharma, Y., & Balamurugan, B. (2020). Preserving the privacy of electronic health records using blockchain. Procedia Computer Science, 173, 171-180.

[36] Singh, Y., Jabbar, M., Shandilya, S. K., Vovk, O., & Hnatiuk, Y. (2023). Exploring applications of blockchain in healthcare: road map and future directions. Frontiers in Public Health, 11.

[37] Stafford, T. F., & Treiblmaier, H. (2020). Characteristics of a blockchain ecosystem for secure and sharable electronic medical records. IEEE Transactions on Engineering Management, 67(4), 1340-1362.

[38] Taherdoost, H. (2023). Blockchain and Healthcare: A Critical Analysis of Progress and Challenges in the Last Five Years. Blockchains, 1(2), 73-89.

[39] Uddin, M. (2021). Blockchain Medledger: Hyperledger fabric enabled drug traceability system for counterfeit drugs in pharmaceutical industry. International Journal of Pharmaceutics, 597, 120235.

[40] Velmovitsky, P. E., Bublitz, F. M., Fadrique, L. X., & Morita, P. P. (2021). Blockchain applications in health care and public health: increased transparency. JMIR Medical Informatics, 9(6), e20713.

[41] Yaqoob, I., Salah, K., Jayaraman, R., & Al-Hammadi, Y. (2021). Blockchain for healthcare data management: opportunities, challenges, and future recommendations. Neural Computing and Applications, 1-16.

[42] Yeung, K. (2021). The health care sector's experience of blockchain: A cross-disciplinary investigation of its real transformative potential. Journal of Medical Internet Research, 23(12), e24109.

[43] Zeng, S.-Q., Huo, R., Huang, T., Liu, J., Wang, S., & Feng, W. (2020). Survey of blockchain: principle, progress and application. Journal on Communications, 41(1), 134-151.