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REVOLUCIONAR A GESTÃO DE DADOS EM SAÚDE: TECNOLOGIA BLOCKCHAIN E SUAS APLICAÇÕES
REVOLUTIONIZING HEALTHCARE DATA MANAGEMENT: BLOCKCHAIN TECHNOLOGY AND ITS APPLICATIONS
REVOLUCIONANDO LA GESTIÓN DE DATOS EN SALUD: TECNOLOGÍA BLOCKCHAIN Y SUS APLICACIONES

Pedro Melo[1,2] *https://orcid.org/0009-0000-0985-0616*
Carlos Cunha[1,2] *https://orcid.org/0000-0002-4165-7477*

[1] Instituto Politécnico de Viseu, Viseu, Portugal
[2] CISeD – Centro de Investigação em Serviços Digitais, Viseu, Portugal

Pedro Melo - pmelo@gmail.com | Carlos Cunha - cacunha@estgv.ipv.pt

Corresponding Author:
Carlos Cunha
Campus Politécnico de Repeses
3504-510 – Viseu - Portugal
cacunha@estgv.ipv.pt

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RESUMO

Introdução: A indústria da saúde enfrenta obstáculos significativos na gestão de dados sensíveis de pacientes, garantindo a integridade dos dados e mantendo a confiança entre as partes interessadas. A tecnologia Blockchain Distributed Ledger (DLT) oferece uma solução promissora ao fornecer capacidades de manutenção de registos seguros, transparentes e à prova de manipulação.
Objetivo: Contribuir para uma avaliação abrangente dos benefícios e limitações da blockchain na área da saúde, destacando seu potencial para fomentar um ecossistema de dados seguro, centrado no paciente e eficiente.
Métodos: Revisão sistemática da literatura, seguindo as diretrizes PRISMA, para analisar a integração da tecnologia blockchain na área da saúde. A análise da investigação divide-se em cinco domínios: implementação técnica, segurança e privacidade, requisitos de recursos, conformidade regulatória e barreiras organizacionais.
Resultados: Os resultados destacam a necessidade de esforços colaborativos entre as partes interessadas da saúde, tecnólogos e reguladores para enfrentar os desafios técnicos e organizacionais, possibilitando a integração prática da blockchain nos sistemas globais de saúde.
Conclusão: Esta investigação evidenciou o potencial da tecnologia blockchain para promover um ecossistema de dados de saúde mais seguro, eficiente e centrado no doente, através de uma análise abrangente das suas implementações e dos resultados observados em contextos reais. Contudo, a integração bem-sucedida desta tecnologia depende da colaboração entre os diferentes intervenientes do setor da saúde, os especialistas em tecnologia e as entidades reguladoras, de forma a ultrapassar os desafios técnicos, organizacionais e regulamentares associados à sua adoção.

Palavras-chave: Blockchain; segurança de dados em saúde; RGPD; interoperabilidade

ABSTRACT

Introduction: The healthcare industry faces significant hurdles in managing sensitive patient data, ensuring data integrity, and maintaining trust among stakeholders. Blockchain Distributed Ledger Technology (DLT) offers a promising solution by providing secure, transparent, and tamper-proof record-keeping capabilities.
Objective: To contribute to a comprehensive assessment of the benefits and limitations of blockchain in the healthcare sector, highlighting its potential to foster a secure, patient-centred, and efficient data ecosystem.
Methods: A systematic review of the literature, following the PRISMA guidelines, to analyse the integration of blockchain technology in the healthcare sector. The analysis of the research is divided into five areas: technical implementation, security and privacy, resource requirements, regulatory compliance, and organisational barriers.
Results: The findings underscore the need for collaborative efforts among healthcare stakeholders, technologists, and regulators to address technical and organizational hurdles, enabling practical blockchain integration into global healthcare systems.
Conclusion: This research highlighted the potential of blockchain technology to foster a more secure, efficient, and patient-centered health data ecosystem through a comprehensive analysis of its implementations and the results observed in real-world contexts. However, the successful integration of this technology depends on collaboration among different stakeholders in the healthcare sector, technology experts, and regulatory bodies, in order to overcome the technical, organizational, and regulatory challenges associated with its adoption.

Keywords: Blockchain; healthcare data security; GDPR; interoperability

RESUMEN

Introducción: La industria de la salud enfrenta obstáculos significativos en la gestión de datos sensibles de pacientes, garantizando la integridad de los datos y manteniendo la confianza entre las partes interesadas. La tecnología Blockchain Distributed Ledger (DLT) ofrece una solución prometedora al proporcionar capacidades de mantenimiento de registros seguros, transparentes y a prueba de manipulaciones.
Objetivo: Contribuir a una evaluación exhaustiva de las ventajas y limitaciones de la cadena de bloques en el ámbito sanitario, destacando su potencial para fomentar un ecosistema de datos seguro, centrado en el paciente y eficiente.
Métodos: Revisión sistemática de la literatura, siguiendo las directrices PRISMA, para analizar la integración de la tecnología blockchain en el ámbito sanitario. El análisis de la investigación se divide en cinco ámbitos: implementación técnica, seguridad y privacidad, requisitos de recursos, cumplimiento normativo y barreras organizativas.
Resultados: Los resultados subrayan la necesidad de esfuerzos colaborativos entre las partes interesadas de la salud, tecnólogos y reguladores para abordar los desafíos técnicos y organizacionales, posibilitando la integración práctica de blockchain en los sistemas globales de salud.
Conclusión: Esta investigación ha puesto de manifiesto el potencial de la tecnología blockchain para promover un ecosistema de datos sanitarios más seguro, eficiente y centrado en el paciente, mediante un análisis exhaustivo de sus implementaciones y de los resultados observados en contextos reales. No obstante, la integración satisfactoria de esta tecnología depende de la colaboración entre los diferentes actores del sector sanitario, los expertos en tecnología y los organismos reguladores, con el fin de superar los retos técnicos, organizativos y normativos asociados a su adopción.

Palabras clave: Blockchain; seguridad de datos en atención sanitaria; RGPD; interoperabilidad

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INTRODUCTION

The healthcare industry faces significant challenges in managing sensitive patient data, ensuring data integrity, and maintaining trust among stakeholders (Zarour et al., 2021). Traditional healthcare systems often struggle with opaque processes, data silos, and vulnerabilities to fraud, which can compromise patient care and operational efficiency (Management, 2023). These issues highlight the need for innovative solutions that can enhance data security, transparency, and patient control over their health information.

Blockchain technology has the potential to revolutionize healthcare by improving trust, security, and transparency among stakeholders. Its distributed ledger technology (DLT) provides secure, transparent, and tamper-proof recordkeeping capabilities throughout the healthcare ecosystem (J et al., 2023). These characteristics can address opaque processes and fraud susceptibility and give patients more control over their health information on healthcare systems (Tanwar et al., 2020).

This article explores the potential of blockchain to revolutionize healthcare data management. The research delves into five critical domains: (1) technical implementation, (2) security and privacy, (3) resource requirements, (4) regulatory compliance, and (5) organizational barriers. An analysis of these domains contributes to a comprehensive evaluation of blockchain's benefits and limitations in healthcare, highlighting its potential to foster a secure, patient-centric, and efficient data ecosystem. It underscores the necessity for collaborative efforts among healthcare stakeholders, technologists, and regulators to address technical and organizational hurdles, paving the way for the practical integration of blockchain into global healthcare systems.

The remainder of this article is organized as follows. Section 2 reviews the related work. Section 3 provides the analysis. Section 4 concludes the article with final thoughts and findings.

1. LITERATURE REVIEW

This section offers a review of current blockchain-based work within the healthcare sector. It is the result of a search on the Scopus platform with the initial search criteria set as ”blockchain” AND (”health” OR ”healthcare” OR ”clinical” OR ”medical”). Documents published from 2020 onward were retained at the screening stage to ensure the most current findings. A limited number of foundational and frequently cited works published before 2020 (e.g., Angraal et al., 2017; Kumar et al., 2018; Pirtle and Ehrenfeld, 2018; Agbo et al., 2019; Shahnaz et al., 2019; Yaeger et al., 2019; Hasselgren et al., 2019) were nonetheless deliberately retained, because they establish the conceptual and theoretical foundations of blockchain in healthcare and are repeatedly cited by the more recent literature. The selection followed the four phases of the PRISMA framework — identification, screening, eligibility, and inclusion. In the identification phase, the initial Scopus query returned 9,022 documents. In the screening phase, records were filtered by language, document type, and the presence of the target terms (“blockchain”, “health”, “healthcare”, “clinical”, “medical”) in the title, after which duplicate and unpublished records were removed. In the eligibility phase, the remaining records were assessed against explicit exclusion criteria: papers published before 2021 that had received no citations, papers not cited in any other study, papers whose full text was inaccessible, and papers whose abstracts revealed no substantive engagement with blockchain applications in healthcare. To minimize selection bias, titles and abstracts were screened against these predefined criteria and borderline cases were re-examined before a final inclusion decision was reached. This process yielded 170 relevant papers, which formed the corpus underpinning this review. From this corpus, the studies most directly addressing the five analytical domains examined in Section 2 were selected for the narrative synthesis; these 37 studies are the works cited throughout this article and compiled in the References.

Anik et al. (2023) reviewed the integration of blockchain technology into EHR systems, highlighting its potential to empower patients by enhancing control, access, and transparency over their medical data. Blockchain addresses challenges in current EHR systems, such as data breaches and inefficiencies, through decentralization, smart contracts, and immutable ledgers. However, limitations include scalability, transaction costs, and regulatory needs. Angraal et al. (2017) evaluated blockchain's decentralization and immutability, examining case studies to highlight opportunities and limitations. Key findings include blockchain's ability to secure patient data and streamline information sharing among providers while noting challenges such as scalability, regulatory compliance, and integration with existing systems. Abbate et al. (2023) proposed a blockchain platform tailored for Healthcare 4.0 that integrates telemedicine services and enhances interoperability across healthcare systems using smart contracts to automate patient consent and claims management processes. The authors highlight limitations in existing solutions, such as poor dissemination of test results and fragmented data systems, which can lead to medical errors. They advocate for broader sharing of test results and emphasize the need for more randomized controlled trials to validate blockchain-based platforms in telemedicine research. Pirtle and Ehrenfeld (2018) explored blockchain technology to improve patient control over health data in patient-driven interoperability. The study found that blockchain can ensure data integrity, reduce data loss risk, and provide transparent audit trails. However, it also introduces security, privacy, infrastructure, incentives, and governance challenges. Persistent issues in blockchain adoption include scalability, privacy, security, patient engagement, and data-sharing incentives.

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The study by Firouzi et al. (2023) explores the integration of IoT, AI, edge–fog–cloud computing, and blockchain in healthcare. This convergence addresses IoT challenges like security, latency, and scalability, enhancing privacy, data management, and operational efficiency. A case study on stress monitoring demonstrates practical implementation using federated learning to protect patient data. Shahnaz et al. (2019) present a framework for implementing blockchain technology in EHRs. The framework uses a permissioned blockchain with smart contracts for access control, combines symmetric and asymmetric encryption for data security, and utilizes off-chain storage for clinical data. The study acknowledges limitations in confidentiality and scalability when data is stored on the blockchain. Younis et al. (2022) propose a blockchain-based solution for secure and privacy-preserving data access in healthcare. Patients can manage access permissions securely, while healthcare organizations comply with privacy regulations. Sensor data is stored in the cloud, with access control and logs managed on the blockchain.

The solution introduces data-driven authentication and secure communication protocols to mitigate fraud and identity theft. Smart contracts regulate stakeholder interactions. However, limitations include the need for additional security measures and risks related to identity theft and encryption key management. Yongjoh et al. (2021) demonstrated a nationwide blockchain implementation for healthcare. The consortium blockchain platform, integrated with mobile apps and decentralized access, enhances data retrieval and security and reduces data loss. The system enables seamless interconnectivity among hospitals via the MQTT protocol using software agents and Raspberry Pi devices. Chelladurai and Pandian (2022) present a blockchain-based healthcare system to address challenges in managing health records. Experiments demonstrate its efficacy in securely processing health records. Key features include decentralized storage and tamper-proof management. The study emphasizes the need for secure storage, privacy, and standardized protocols for interoperability in blockchain-based healthcare applications. Bazel et al. (2021) introduced a blockchain-based framework for managing healthcare data. It offers real-time access to patient data, enhanced privacy through patient-controlled permissions, and secure data sharing. It also facilitates global connections for improved treatment options.

2. METHODS

This research aims to explain how blockchain technology can address problems in healthcare data management. Specifically, the objectives of this study are defined as the challenges to its adoption, as depicted in Table 1.

The five domains analyzed in this study constitute the taxonomy used to organize the challenges identified across the 170 papers in the corpus. This taxonomy was derived inductively from the themes that recurred most consistently in the reviewed literature, grouping the obstacles to blockchain adoption into five complementary dimensions. Technical implementation concerns the feasibility of deploying and scaling blockchain within existing healthcare infrastructures. Security and privacy address the protection of sensitive patient data and the integrity of the system. Resource requirements capture the financial, infrastructural, and human costs of adoption. Regulatory compliance relates to the alignment of blockchain with legal frameworks such as the GDPR and HIPAA. Organizational barriers encompass the cultural, managerial, and skills-related factors that condition adoption in practice. Table 1 summarizes these challenges and maps the studies that address each domain to its corresponding category, after which each domain is examined in detail in the subsections that follow.

Table 1 - Summary of Challenges of Blockchain Technology in Healthcare

Context	Challenge	Studies
Technical Implementation	Scalability issues, high computational requirements, and integration complexity with legacy systems	Kumar et al. (2018); Louis and Maheshwari (2023); Auwal (2023); Rattanawiboomsom et al. (2023); Atadoga et al. (2024)
Security and Privacy	Smart contract vulnerabilities, private key management risks	Agbo et al. (2019); Zaman et al. (2021); Adeghe et al. (2024); Adeoye and Adams (2024); Atadoga et al. (2024)
Resource Requirements	High infrastructure costs, training requirements	Yaeger et al. (2019); Benaich et al. (2023); Taherdoost (2023); Altamimi et al. (2024); Quayson et al. (2024); Shah et al. (2024)
Regulatory Compliance	Data protection regulations, lack of standardization, HIPAA compliance	Agbo et al. (2019); Hasselgren et al. (2019); Hasselgren et al. (2020); Chukwu and Garg (2020); Durneva et al. (2020); Schmeelk et al. (2022); Arbabi et al. (2023)
Organizational Barriers	Professional resistance, workflow disruption, limited technical expertise	Durneva et al. (2020); Velmovitsky et al. (2021); Alzahrani et al. (2022)

3. RESULTS

3.1 Technical Implementation

One of the primary concerns related to implementing blockchain in healthcare is scalability. As the volume of healthcare data continues to grow, blockchain systems may struggle to handle this increased demand effectively. Scalability limitations inherently arise from requiring every blockchain transaction to be validated by multiple nodes, which can significantly slow down transaction

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processing speeds. As the demand increases, the time factor for transaction processing may elongate, making it challenging to maintain efficiency in high-demand environments such as healthcare (Louis and Maheshwari, 2023). Moreover, integrating blockchain solutions often concerns energy consumption and infrastructure costs, as maintaining a blockchain system is computationally intensive (Auwal, 2023).

Computational requirements for blockchain are substantial. Nodes involved in the network undertake complex cryptographic processes to validate transactions and secure data. This high computational demand can burden existing healthcare computing resources, which are often outdated and not designed to support such technology (Atadoga et al., 2024; Auwal, 2023) (e.g., the computational power needed for consensus mechanisms).

Another critical challenge is the integration complexities with legacy systems. Many healthcare organizations utilize legacy information systems not designed to be compatible with new technologies such as blockchain. Transitioning to a new blockchain-based system requires significant data migration and interoperability efforts to ensure that all systems can communicate effectively (Kumar et al., 2018). The lack of standardized protocols and service agreements among healthcare providers further exacerbates these complexities. Different healthcare systems may have distinct methods for patient data management, leading to difficulties in achieving interoperability among disparate platforms (Rattanawiboomsom et al., 2023).

3.2 Security and Privacy

The vulnerabilities associated with smart contracts, risks in private key management, and compliance challenges with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) constitute major barriers to the effective use of blockchain in healthcare. Smart contracts hold the terms directly written into code. Although they enhance operational efficiencies by automating processes, they are susceptible to coding errors and security breaches that malicious actors can exploit. These attacks can lead to unauthorized access to sensitive patient data, thereby threatening patient confidentiality and overall system integrity (Agbo et al., 2019). Moreover, historical incidents of breaches in blockchain networks, particularly those associated with cryptocurrencies, underscore the urgent need to systematically address this vulnerability to ensure that patient data remains intact (Atadoga et al., 2024).

Risks associated with private key management serve as another critical area of concern. Private keys are crucial for encrypting and decrypting sensitive data stored on the blockchain. If these keys are lost, stolen, or mismanaged, unauthorized parties can manipulate or access sensitive health information (Adeghe et al., 2024). Reports indicate that inadequate private key management procedures can lead to significant risks, which require the development of strict security protocols to safeguard these keys and ensure that only authorized personnel have access to sensitive patient information (Zaman et al., 2021).

To overcome these challenges, several strategies can be implemented. First, enhancing smart contract security through rigorous auditing processes, standardized development practices, and the incorporation of advanced security features such as multi-signature wallets could significantly reduce vulnerabilities (Adeghe et al., 2024). Additionally, creating comprehensive frameworks for private key management, including the use of hardware security modules and user education on best practices, is essential for mitigating the risks associated with private keys (Adeoye and Adams, 2024).

3.3 Resource Requirements

Deploying blockchain solutions requires not only robust technological designs but also the capability to integrate existing systems seamlessly. This complexity leads to elevated costs related to hardware, software, and additional technologies required for implementation (Yaeger et al., 2019). Current financial evaluations suggest that without clear economic incentives, many organizations view blockchain as unaffordable, particularly compared to traditional data management systems (Taherdoost, 2023). Plus, blockchain systems require ongoing updates, monitoring, and security checks to ensure data integrity and compliance with regulatory standards (Shah et al., 2024). The dynamic nature of blockchain technology also necessitates that organizations stay informed about evolving best practices and updates, which adds to operational costs (Benaich et al., 2023).

These challenges can be mitigated by optimizing blockchain protocols and employing hybrid models to enhance system efficiency and reduce costs, making blockchain solutions more appealing (Quayson et al., 2024). Future research and pilot programs should focus on identifying economically viable implementations that demonstrate tangible benefits, which may help alleviate initial cost concerns (Taherdoost, 2023). Furthermore, a collaborative approach involving stakeholders from various sectors could lead to shared resource models, lowering individual burdens related to infrastructure and maintenance (Altamimi et al., 2024).

3.4 Regulatory Compliance

Blockchain in healthcare faces regulatory hurdles that center on data privacy and systems integration. Several studies report that patient privacy requirements – especially those imposed by the GDPR and HIPAA – clash with blockchain's inherent immutability. Conflicts may arise between the right to erasure and the permanent record of the blockchain (Hasselgren et al., 2019). Also, there are challenges in balancing patient privacy with data accessibility and interoperability (Arbabi et al., 2023) In addition, performance

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constraints, storage trade-offs, and integration with existing Electronic Health Record systems emerge as technical barriers (Chukwu and Garg, 2020; Schmeelk et al., 2022).

Several evidence-based strategies have been proposed to mitigate these challenges, employing private permissioned blockchains to enhance data privacy and control access, as the French National Commission on Informatics and Liberty recommendations (Durneva et al., 2020). Another key strategy is storing sensitive patient data off-chain while recording metadata on-chain, which helps reconcile blockchain's immutability with GDPR's right to erasure (Agbo et al., 2019). Optimizing on-chain and off-chain storage is suggested to address performance and scalability issues, and developing interoperable standards, such as FHIR-based architectures, is proposed to facilitate smooth integration with legacy healthcare systems (Hasselgren et al., 2020). These findings underscore the need for targeted technical adaptations and clear guidelines to align blockchain innovations with regulatory requirements in healthcare.

3.5 Organizational Barriers

Blockchain adoption in healthcare encounters barriers that span technical shortcomings and disruptive organizational dynamics – e.g., shortage of IT skills coupled with challenges in cryptographic complexity and key management (Velmovitsky et al., 2021). Shifts in culture, infrastructure, and business practices unsettle established routines (Alzahrani et al., 2022). Other key obstacles are user resistance and limited management support (Durneva et al., 2020). Organizational strategies advocate readiness scoring models, targeted training, and structured change management to enhance stakeholder engagement and smooth the transition. These findings collectively delineate the challenges and actionable remedies encountered when employing blockchain in healthcare.

CONCLUSION

This article has explored the transformative potential of blockchain technology in addressing the critical challenges faced by the healthcare industry in managing sensitive patient data, ensuring data integrity, and maintaining trust between stakeholders. Blockchain distributed ledger technology offers a robust solution by providing secure, transparent, and tamper-proof record-keeping capabilities, which are essential for enhancing data security, transparency, and patient control over their health information. This research has highlighted blockchain's potential to foster a secure, patient-centric, and efficient data ecosystem through a comprehensive review of real-world implementations and outcomes. However, successful integration of blockchain technology requires collaborative efforts among healthcare stakeholders, technologists, and regulators to address technical and organizational hurdles.

As the healthcare industry continues to evolve, blockchain technology stands out as a promising innovation that can revolutionize data management practices, ultimately improving patient care and operational efficiency. Future research and development should focus on overcoming the identified challenges and leveraging the full potential of blockchain to create a more secure, interoperable, and patient-centered healthcare system.

AUTHOR´S CONTRIBUTION

Conceptualization, P.M. and C.C.; data curation, P.M. and C.C.; formal analysis, P.M. and C.C.; funding acquisition, C.C.; investigation, P.M. and C.C.; methodology, P.M. and C.C.; project administration, C.C.; resources, C.C.; software, C.C.; supervision, C.C.; validation, C.C.; visualization, P.M. and C.C.; writing – original draft, P.M. and C.C.; writing – review and editing, P.M. and C.C.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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