Rev. Fac. Med. Hum. 2024; 24(1):144-161.
DOI: 10.25176/RFMH.v24i1.5900
REVIEW ARTICLES

ISSN Versión Online: 2308-0531
Facultad de Medicina Humana URP
RFMH

BLOCKCHAIN TECHNOLOGY APPLIED IN MEDICINE: A SYSTEMATIC REVIEW

TECNOLOGÍA BLOCKCHAIN APLICADA EN LA MEDICINA: UNA REVISIÓN SISTEMÁTICA

Christian Jairo Tinoco-Plasencia [1,a]

REVIEW ARTICLES

ABSTRACT

Objective: Develop an articles review to evaluate the existing evidence on blockchain technology applied in medicine. **Methods:** The study was of a documentary type, bibliographic design, framed in a systematic review. The harvest of articles was carried out in the Scopus, Web of Sciences, Pro Quest and ScienceDirect databases from January 1, 2018 to July 31, 2023. The descriptors were blockchain, technology and medicine. The PRISMA diagram was prepared considering the inclusion criteria: original articles, with open access; that address the subject and in any language. The search yielded 70 articles, of which 11 formed the sample. **Results:** The various applications of blockchain technology in medicine were discussed, including its integration with artificial intelligence (AI) for data-centric analysis; regarding the development of traceability systems, however, its greatest applicability is in the registration of medical records of patients, whose application was successful. Despite this, its incipient use in medicine was verified due to the lack of studies in this regard. **Conclusions:** The application of blockchain technology in medicine is very scarce, despite the potential it has for the registration and safeguarding of medical data, therefore, its study should be deepened.

Keywords: Blockchain; Artificial Intelligence; Traceability; Medical Records. (Source: MESH-NLM)

RESUMEN

Objetivo: Desarrollar una revisión de artículos para evaluar la evidencia sobre la tecnología blockchain aplicada en la medicina. **Métodos:** El estudio es de tipo documental, diseño bibliográfico, enmarcado en una revisión sistemática. La recolección de los artículos se realizó en las bases de datos Scopus, Web of Sciences, Pro Quest y SienceDirect, desde el 1 de enero de 2018 hasta el 31 de julio de 2023. Los descriptores fueron blockchain, tecnología y medicina. Se elaboró el diagrama PRISMA y se consideró los criterios de inclusión: artículos originales, con acceso abierto que aborden el tema y en cualquier idioma. Se hallaron 70 artículos, de los cuales 11 conformaron la muestra. **Resultados:** Se analizaron las diversas aplicaciones de la tecnología blockchain en la medicina, entre ellas su integración con inteligencia artificial (IA) para el análisis centrado en datos; en cuanto al desarrollo de sistemas de trazabilidad, sin embargo, su mayor aplicabilidad está en el registro de historias médicas de pacientes, cuya aplicación fue exitosa. A pesar de esto, se comprobó su uso incipiente, en la medicina, debido a la ausencia de estudios al respecto. **Conclusiones:** La aplicación de la tecnología blockchain en la medicina es muy escasa, a pesar del potencial que posee para el registro y resguardo de datos médicos; por lo tanto, se debe profundizar el estudio de la misma.

Palabras clave: Blockchain; Inteligencia Artificial; Trazabilidad; Historias Médicas. (Fuente: DeCS- BIREME)

[1] Escuela de Posgrado, Universidad Ricardo Palma(URP). Lima, Perú. South America.
[a] Doctorando en Administración de Negocios Globales, URP, MBA, Ingeniero Industrial, Docente Investigador Renacyt.

Cite as: Tinoco-Plasencia CJ. Blockchain technology applied in medicine: a systematic review. Rev Fac Med Hum. 2024;24(1):144-161.
doi 10.25176/RFMH.v24i1.5900

Journal home page: http://revistas.urp.edu.pe/index.php/RFMH

INTRODUCTION

Given the undeniable technological advancements in the field of medicine, there arises the need to incorporate blockchain technology into this area, which involves a database that allows for the collection and storage of large amounts of information that can be shared in a decentralized manner. Its growth has been substantial over the last decade. Considered as the fundamental basis of cryptocurrencies, including Bitcoin, various authors have analyzed its application in other fields due to its characteristics of security and privacy. In this regard, it has been used in medicine for different purposes, such as data recording, transactions, and maintenance through smart contracts[1].

Indeed, the emergence of blockchain technology, as a responsible and transparent way to store and distribute information, is creating the foundation to address serious issues of privacy, security, and data integrity in the field of medicine [2]. In a general context, blockchain technology is a tool for the distributed ledger of digital data transactions through a peer-to-peer (P2P) network, which can be distributed publicly or privately to users, allowing for the reliable and verifiable storage of any type of information[3,4]. On the other hand, unlike other types of databases managed by third parties, blockchain is a decentralized chain of blocks, implying that no single user can control its transactions personally. Decentralization is a fundamental characteristic of blockchain, as it gives control to the system rather than the user, allowing for greater transparency and security [5,6].

Within this framework, the management of blockchain technology has five basic principles: the first is constituted in data control, which is independent; that is, no one controls the data, however, each user can verify their records; the second is communication, which only occurs between peers; the third indicates that users can remain anonymous or provide proof of their identity; the fourth principle refers to the fact that current transactions cannot be changed; finally, the fifth principle indicates that each transaction is linked to the previous one [7,8]. Among the challenges facing the medical industry, one of the principals is the lack of secure and reliable mechanisms for data storage and access. In this sense, blockchain technology allows information to be stored and shared in a secure and decentralized way, which restricts unauthorized individuals from modifying it. Additionally, this technology has the ability to track the history and authenticity of medical products, such as prescribed medicines and medical devices. This capability allows for the identification of adulterations and ensures that patients receive genuine and safe medications. In this context, blockchain provides a mechanism for pharmaceutical companies to achieve complete traceability of a medication, allowing them to reliably access production data, reported side effects, and supervision of the necessary conditions for its transportation and storage[11].

In this regard, the study by Farahat et al.[12] proposes the design of an IoMT (Internet of Medical Things) system to store patients' medical information, which is remotely sent via the internet. The proposed model suggests that each medical record is stored through blockchain technology, using a block connected to the previous one by a hash function: a cryptographic operation that produces unique and irreversible identifiers from a given data[13].

Similarly, the study by Sonkamble et al.[14] addresses the decentralized management of patients' medical data within the framework of blockchain-based electronic health records (EHR) to ensure confidentiality, access control, and record privacy. The architecture of this model was patient-centered and focused on the secure storage control of their data in EHRs. Likewise, the study by Mendoza et al. analyzes the use of blockchain to generate an algorithm that develops a smart contract for users of a medical records platform. This algorithm helps to solve the authentication and reliability issues of access to healthcare platforms. The study proposes an algorithm in which medical history management operations are executed and integrated automatically in a distributed environment.

In a different context, the study by Albakri & Alqahtani proposes the development of an IoMT through an intelligent blockchain-based smart healthcare system, which employs encryption with an optimal deep learning model (BSHS-EODL). The BSHS-EODL method allows for the secure transmission of blockchain-assisted images and diagnostic models for the IoMT environment. This model combines data classification, data collection, and image encryption. Despite these evidences, there are a number of challenges associated with the use of blockchain technology for designing

REVIEW ARTICLE

medical information networks, including patient perception towards such networks, security and privacy risks, transparency in data exchange, processing requirements, and implementation costs [16,17]. Additionally, there are inherent limitations and restrictions of blockchain technology, such as mining incentives, mining threats, key management, as well as data security and confidentiality; not to mention legislative constraints, the absence of laws regulating the use of blockchain technology in medicine, which generally require permissions, scalability, and agreements for sharing records[19].

One of the most relevant aspects for adopting blockchain technology in medicine is data security. In this regard, most healthcare providers and hospitals have improved their data security precautions. However, current firewalls for medical data can hinder medical research and collaboration in healthcare treatment. On the contrary, cloud computing and the use of big data involve sharing medical data among various users and organizations, which is necessary to enable analysis and provide more effective healthcare services, as well as innovative treatment plans [20,21,22]. Indeed, with the application of blockchain, the widespread use of patients' medical information could pose challenges in terms of processing, costs, and limited scalability. At the same time, ethical dilemmas may arise, as improper handling could compromise or infringe upon patients' right to maintain the anonymity of their medical history [23,24,25].

Considering that the security and privacy of medical data are crucial elements that must be ensured, it is essential to preserve the confidentiality, integrity, and authentication of the server during data transfer. The main goal is to share health data in a practical way, using various approaches to achieve the ultimate goals. Blockchain-based storage and infrastructure platforms offer a new perspective in medical informatics, with several advantages over traditional methods[26,27,28].

However, there are several examples of this model implemented in medicine, such as MedicalChain, designed to address issues such as slow access times to medical information, the disaggregation of a patient's records across different medical institutions, and security risks in safeguarding medical information, among others. To address these issues, the proposal suggests that patients have a single verified and reliable electronic record containing their entire medical history that can be shared with doctors to facilitate new diagnoses[29].

Similarly, various proposals have been developed, such as the case of Lluncor et al.[30], who developed a blockchain-based model with the purpose of preventing the alteration of forensic medical reports from the Instituto de Medicina Legal y Ciencias Forenses of Cajamarca, Peru. The proposal considers an improved model based on blockchain technology to strengthen the security of the content of FME reports, generated through the DICEMEL System (Central Forensic Medical Division System). These reports are processed in the administrative and medical fields and are requested by competent authorities such as the Peruvian National Police, Criminal Prosecution Offices, DEMUNA, and the Judiciary, among others.

Currently, IBM is immersed in the development of its Healthchain initiative, which aims to centralize patients' medical information in Latin America through the implementation of blockchain technology on IBM Cloud. This initiative seeks to enhance patient care by promoting precision medicine and automating administrative tasks, while ensuring the integrity of the information. Additionally, the application of blockchain could increase the effectiveness of diagnoses made by AI robots by collecting large volumes of validated information[31].

Based on the foregoing considerations, the execution of the present systematic review study is proposed with the aim of evaluating the evidence on blockchain technology applied in medicine. In summary, the study aims to determine the scientific information about blockchain technology applied in medicine, in order to systematize the studies and the most relevant findings achieved in the field and establish recommendations. On the other hand, the first specific objective consists of identifying the applications that have been given to blockchain technology in medicine, in order to evaluate the current scope of application. Meanwhile, the second specific objective refers to specifying the findings obtained in the studies where blockchain technology was applied in medicine, with the purpose of evaluating its performance and establishing the respective conclusions.

METHODS

Type and design of the research

The study is documentary in nature, characterized by focusing on the process of searching, analyzing, and interpreting secondary information, obtained from studies conducted by other authors from documentary sources[32]. Likewise, the design is bibliographic, which consists of interpreting data reported by bibliographic sources or if there is not enough knowledge to obtain information from reality[33]. Furthermore, the present study was framed in a systematic review, which the Cochrane Handbook for Systematic Reviews of Interventions[34] defines as studies with clear objectives, pre-defined eligibility criteria, explicit and repeatable methodology, systematic search, assessment of validity, organized presentation, synthesis of characteristics, and results of the same.

Additionally, the present study was based on the Preferred Reporting Item for Systematic Reviews (PRISMA) declaration. This methodology is a guide for conducting comprehensive systematic review studies, for which advances in techniques for selecting, analyzing, and synthesizing research are considered [35].

Search strategies

The articles for the systematic review were searched in the databases: Scopus, Web of Sciences, Pro Quest, and ScienceDirect, and the specific search engines of each one were used. The search process was conducted from January 1, 2018, to July 31, 2023. For this purpose, a series of descriptors or keywords were used to accurately identify studies developed on the topic. In this regard, the defined descriptors were blockchain, technology, and medicine, which were searched within the title of each publication using the boolean operator: And.

Search procedure

The study was developed following the procedure described in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement, launched in 2009 with the purpose of assisting authors of systematic reviews in transparent documentation of the rationale behind the review, actions taken by the authors, and findings obtained. The updated PRISMA 2020 version replaces the 2009 edition and incorporates a new presentation guide for publications, reflecting advances in methods used to identify, select, evaluate, and synthesize studies [36,37].

According to Linares et al. [38], it is crucial that the review process be meticulously planned from the beginning to minimize biases and discard irrelevant or low-quality studies. A systematic review involves the preparation of a critical and reproducible summary of the results present in publications related to a specific topic or question. With the aim of improving scientific writing, the methodology for conducting a systematic review should be presented in a structured manner.

To determine the population and sample of the study, the flow diagram contemplated in the PRISMA methodology was elaborated, which, according to Ciapponi [39], should describe the various phases of the process: identified records, number of studies included and excluded, and reasons for exclusions. The PRISMA diagram was elaborated considering the following inclusion criteria for articles: 1) original, 2) open access, 3) addressing blockchain technology applied in medicine, 4) developed in any language. Additionally, systematic review articles, letters to the editor, and expert opinions were excluded.

Selection of studies

With the initial search, 70 publications were obtained, and the four selected databases were considered, after applying the descriptors, the Boolean operator, and the defined date range. To refine this search, the previously established inclusion criteria were applied; in this sense, 52 studies were excluded, and the search was reduced to 18 publications, which were reviewed for compliance with the inclusion criteria in terms of title and abstract. Consequently, six duplicate articles were excluded, and one for not containing the variables in the title. Consequently, the sample consisted of 11 articles. Figure 1 shows the PRISMA diagram, which describes the process of search, identification, and selection of the definitive sample of this systematic review study. Similarly, in Figure 2, the number of articles identified in each database in the initial search is presented; it is noteworthy that most publications are indexed in ScienceDirect. Similarly, in Figure 3, the number of articles in the sample published each year is described; in this regard, most of the work was developed during the years 2022 and 2023.

Additionally, these 11 publications underwent a quality evaluation process that allowed conclusions focused on their findings to be derived, and also identified observed limitations, with the aim of conducting a reproducible and bias-free verification. Although there are currently different tools for evaluating the quality of systematic reviews, this study opted to use a verification method that includes the aspects presented in Table 1.

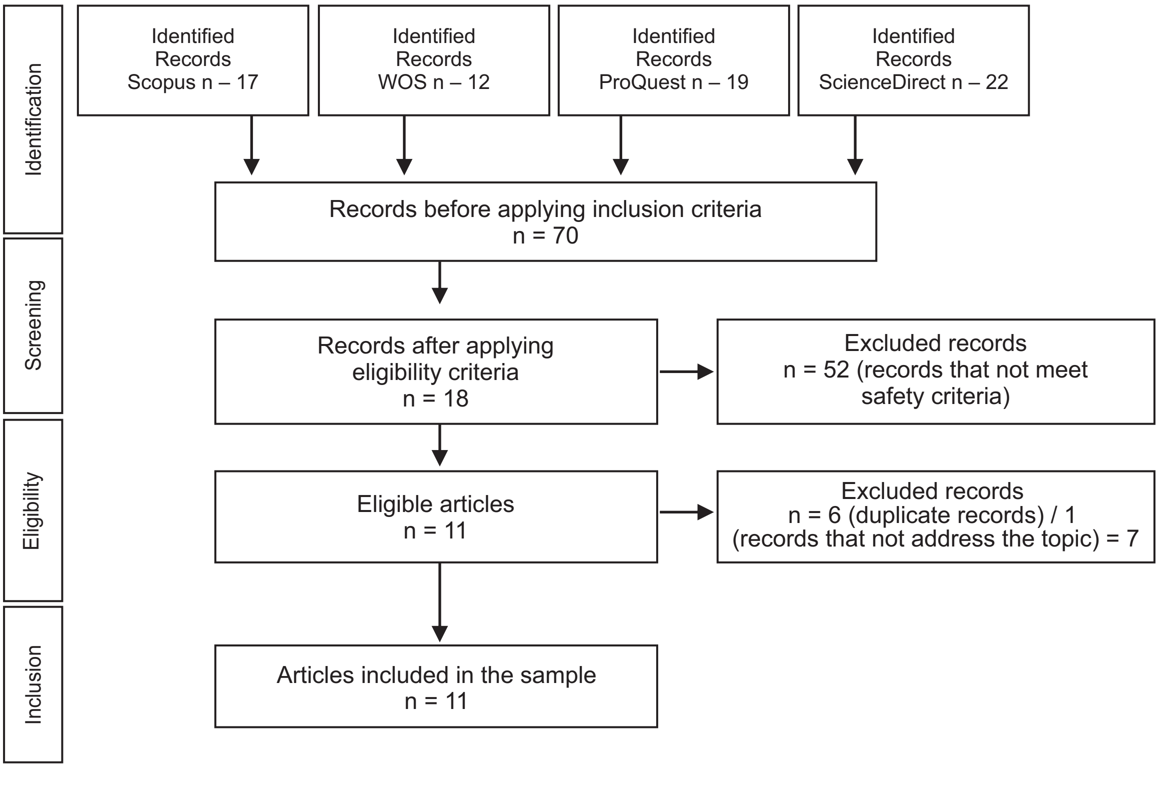
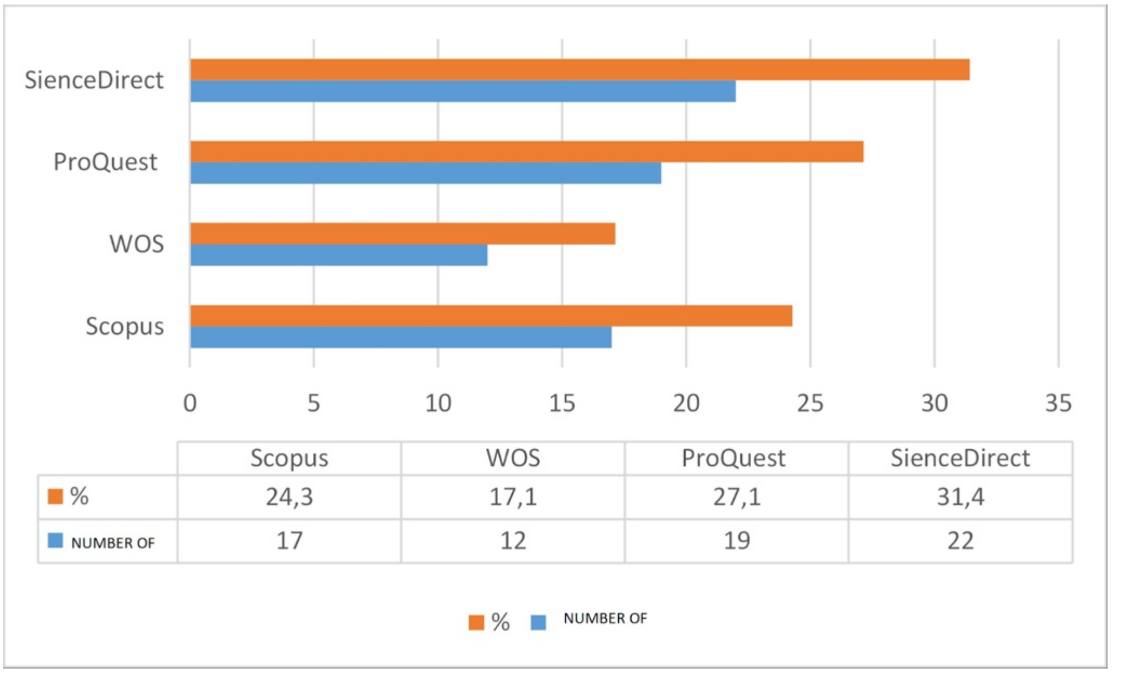


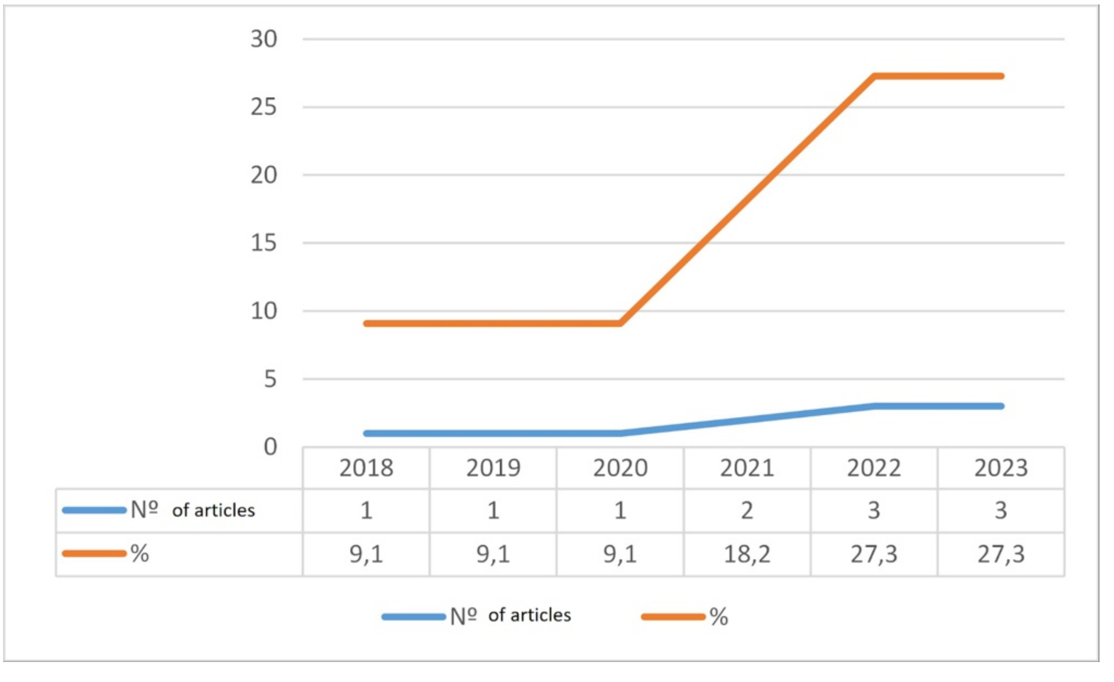
Figure 1. PRISMA flow diagram.



	Scopus	WOS	ProQuest	SienceDirect
%	24,3	17,1	27,1	31,4
NUMBER OF	17	12	19	22

Figure 2. Results of the initial article search.

.



	2018	2019	2020	2021	2022	2023
Nº of articles	1	1	1	2	3	3
%	9,1	9,1	9,1	18,2	27,3	27,3

Figure 3. Results of the number of articles in the sample by year.

Table 1. Aspects of the evaluation of the quality of the selected articles.

Criterion	Description
Timeliness	The selected publications are current studies related to blockchain technology applied in medicine.
Comprehensiveness	The works are the most relevant in the field of study. Additionally, they wer e conducted using valid and reliable instruments.
Scope	From the total number of works found, the sample is considered sufficient. Each one was verified to employ a representative sample.
Risk of bias	According to the gathered evidence, no biases were identified that could question the reliability of the review. Additionally, the studies present cross-sectional designs. The statistical models were correctly applied.
Structuring	The review was conducted in an orderly and systematic manner, following the methodology.
Relevance	The methodologies examined in the chosen studies are appropriate to further explore the topic.
Clarity	From a grammatical and syntactic perspective, the narrative of the review is appropriate, in addition to being clear and easy to understand in its fluency.
Precision	The words used are suitable for the specific vocabulary of the field of study and the elements detailed.

RESULTS

Scientific information about blockchain technology applied in medicine

The selected articles were tabulated considering various aspects: author, publication date, title, journal, and methodology employed, as shown in Table 2. Consequently, the analysis of the information highlights the following: only one article was published in the years 2018, 2019, and 2020, while two in 2021 and three in the years 2022 and 2023. Furthermore, the articles were published in nine different journals. On the other hand, three were developed under a qualitative methodology, while the remaining eight according to a mixed methodology.

Table 2. Selected articles.

Author/Year	Title	Journal	Methodology
Krittanawong et al. (2020)	Integrating blockchain technology with artificial intelligence for cardiovascular medicine	Nature Reviews Cardiology	Cualitativa
Xiao et al. (2023)	Application of Blockchain Sharding Technology in Chinese Medicine Traceability System	Computers, Materials & Continua	Mixta

Li et al. (2022)	An Exploratory Study on the Design and Management Model of Traditional Chinese Medicine Quality Safety Traceability System Based on Blockchain Technology	Security and Communication Networks	Mixta
Radanović & Likić (2018)	Opportunities for Use of Blockchain Technology in Medicine	Applied Health Economics and Health Policy	Cualitativa
Siyal et al. (2019)	Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives	Cryptography	Cualitativa
Ortiz et al. (2023)	Increasing the security and traceability of biological samples in biobanks by blockchain technology	Computer Methods and Programs in Biomedicine	Mixta
Ait et al. (2022)	Design and implementation of a New Blockchain-based digital health passport: A Moroccan case study	Informatics in Medicine Unlocked	Mixta
Garrido et al. (2021)	A simulation-based AHP approach to analyze the scalability of EHR systems using blockchain technology in healthcare institutions	Informatics in Medicine Unlocked	Mixta
Liu et al. (2023)	P-PBFT: An improved blockchain algorithm to support large-scale pharmaceutical traceability	Computers in Biology and Medicine	Mixta
Rehman et al. (2022)	A secure healthcare 5.0 system based on blockchain technology entangled with federated learning technique	Computers in Biology and Medicine	Mixta
Tan et al. (2021)	Retinal photograph-based deep learning algorithms for myopia and a blockchain platform to facilitate artificial intelligence medical research: a retrospective multicohort study	The Lancet Digital Health	Mixta

REVIEW ARTICLE

Applications of blockchain technology in medicine and studied populations

Table 3 presents the most used applications of blockchain technology in medicine; according to the studies that formed the sample, the following stood out: integration with artificial intelligence (AI) for data-centric analysis and information flow in cardiovascular medicine, traditional Chinese medicine (TCM) traceability system, data management for healthcare, electronic medical records management, clinical research, detection of medical fraud, neuroscience, pharmaceutical industry, and biobank management, among others.

REVIEW ARTICLE

Table 3. Applications of blockchain technology in medicine and studied population.

Author/Year	Main applications	Population
Krittanawong et al. (2020)	The study proposes the use of AI in cardiovascular medicine, through blockchain technology, as it provides secure interoperability between stakeholders in silos and centralized data sources. In other words, it seeks the integration of blockchain with AI for data-centric analysis and information flow, its limitations, and potential applications in cardiovascular medicine.	Blockchain technology with AI applied to cardiovascular medicine.
Xiao et al. (2023)	The study analyzes the application of Sharding blockchain technology in the traceability system of TCM. To ensure the quality of TCM, blockchain is implemented to design the origin tracking traceability scheme. Despite these schemes being able to ensure the integrity, shareability, credibility, and immutability of TCM more effectively, many problems are exposed with the rapid growth of data in blockchains, such as expensive overhead costs, performance bottlenecks, and traditional architecture not being suitable for data with dynamic growth. In this regard, a novel and lightweight TCM traceability architecture based on blockchain using sharding (LBS-TCM) is proposed. This architecture employs fragmentation to develop a novel traceability mechanism that supports more convenient operations for TCM requirements, such as loading, querying, and downloading.	Design of a traceability scheme for traditional Chinese medicine.
Li et al. (2022)	The study aims to build a traditional Chinese medicine (TCM) quality safety traceability system based on blockchain technology, through the analysis of the commercial process and supervision characteristics of the TCM supply chain. Blockchain technology is a novel way to apply computer technology, such as distributed data storage, peer-to-peer transmission, consensus mechanism, encryption algorithm, among others. It allows decentralization, non-manipulation, transparent and open handling, and data traceability. The non-manipulation function, hash function, and timestamp can effectively solve the problem of TCM supply chain traceability.	Traceability system, security, and quality of traditional Chinese medicine, based on blockchain.

Radanović & Likić (2018)	The study evaluates potential applications of blockchain in the field of medicine, which could include its use in electronic health records, health insurance, biomedical research, drug procurement and supply processes, and medical education. Specifically, it describes the following applications: electronic health records, public health, education, insurance and acquisition policies, biomedical research, quality, and supply chain management for drug control. It also states that the use of blockchain is not without weaknesses, that this technology is still immature and lacks public or even expert knowledge, making it difficult to have a clear strategic vision of its true potential. Currently, there are issues with scalability, smart contract security, and user adoption.	Blockchain technology in medicine
Siyal et al. (2019)	The study analyzes the application of blockchain technology in data management for healthcare. It also considers the potential of blockchain technology in the field of medicine, genomics, telemedicine, telemonitoring, electronic health, neuroscience, and personalized healthcare applications, due to its data stabilization and security mechanism, allowing users to interact through different types of transactions. Among the applications detailed are the development of electronic health records, clinical research, detection of medical fraud, neuroscience, pharmaceutical industry, and research.	Blockchain technology in medicine.
Ortiz et al. (2023)	The study describes a blockchain smart contract to ensure traceability of processes carried out in a biobank, with the aim of ensuring traceability. One of the main functions of a biobank is to store biological samples under high-quality conditions for future research. Therefore, an application to manage a biobank, based on the web, can perform different tasks: informed consent, confidentiality, non-profit, compliance with quality and safety standards, including traceability of samples	Blockchain smart contract to enhance biobank traceability.
Bennacer et al. (2022)	The study analyzes the design of a private digital health passport based on blockchain, to ensure the protection of sensitive information, security, and privacy among all actors: Government, Ministry of Interior, Ministry of Health, verifiers, complying with the National Commission for the Protection of Personal Data Protection (CNDP) and the Moroccan Law 09-08. A framework solution is proposed, in which two types of actors are identified: authorized and unauthorized, to restrict and control access to citizens' personal information.	Integration of a private digital health passport based on Blockchain for all actors.

REVIEW ARTICLE

Garrido et al. (2021)	The study is based on an AHP approach to analyze the scalability of electronic health record (EHR) systems using blockchain technology in healthcare institutions. It has the aim of selecting the blockchain protocol that provides the best performance for scalability in the implementation of an EHR system based on BT in a high-priority healthcare institution (HP-HI).	Rigorous analysis of three blockchain protocols: Ethereum, Dogecoin, and Bitcoin, and five transaction aspects: sent, received, failed, nodes, and costs
Liu et al. (2023)	The purpose of this study is to analyze an improved blockchain algorithm (P-PBFT) to support large-scale pharmaceutical traceability. This algorithm combined with blockchain technology, called Pharmaceutical-Practical Byzantine Fault Tolerance (P-PBFT) based on PBFT, allows solving problems of high latency, high system overhead, and small scale admitted in the current pharmaceutical traceability application. The algorithm combines the characteristics of a pharmaceutical supply chain, optimizes the consistency protocol in the original algorithm, divides large-scale network nodes into different consensus sets by response speed, and performs clustering consensus.	P-PBFT, blockchain algorithm
Rehman et al. (2022)	The study aims to conduct an analysis of the application of blockchain technology interlinked with federated learning in healthcare 5.0. It proposes the construction of a secure health monitoring system 5.0, through the use of blockchain technology and an intrusion detection system. This will allow detecting malicious activities in a healthcare network and monitoring patients through medical sensors, with the aim of predicting diseases and taking necessary measures. This application will improve the quality of life of patients, as well as reduce stress and healthcare costs. It was found that IoMT allows a series of functions in the field of information technology, one of which is intelligent and interactive healthcare.	Construction of a secure health monitoring system in healthcare 5.0 through blockchain
Tan et al. (2021)	The study seeks to design deep learning algorithms based on retinal photographs for myopia and a blockchain platform to facilitate artificial intelligence medical research. In this regard, deep learning algorithms based on retinal photographs for the detection of myopic macular degeneration and high myopia were developed and tested, using a total of 226,686 retinal images. First, the algorithms were trained and internally validated from Singaporean data, and then externally tested on datasets from China, Taiwan, India, Russia, and the UK. The performance of learning algorithms was also compared with the opinion of six experts, using a randomly selected dataset of 400 images from external datasets. An AI-based blockchain platform was used as a proof of concept to demonstrate real application of secure data transfer, model transfer, and model testing at three sites in Singapore and China.	26,686 retinal images to identify myopic macular degeneration and high myopia were used. 400 images were randomly selected to compare the performance of algorithms and that of six expert evaluators.

Findings obtained in studies where blockchain technology was applied in medicine

The results achieved in the studies that make up the sample are presented in Table 4, highlighting the findings in the use of blockchain to facilitate integration with AI, to establish secure data management, or healthcare platforms. Likewise, results of blockchain use in healthcare systems are presented, to record clinical data and use data standards that can be replicated by other organizations.

Table 4. Findings obtained with the application of blockchain technology in medicine.

Author/Year	Main findings
Krittanawong et al. (2020)	**Relevant finding:** Blockchain represents a natural base for standardizing health data structures for AI training, clinical trials, and regulatory purposes. **Other relevant aspects:** Blockchain technology can accelerate data development through AI applications. For example, neural networks were trained using ECG from a wearable monitor in 53,549 patients, providing diagnostic accuracy at the cardiology level for arrhythmias. The use of blockchain can facilitate the secure integration of data from other healthcare providers or platforms, increasing instances of those arrhythmias in joint data to enhance training. Consequently, there are various strategies for integrating blockchain with AI. A novel challenge would be to combine data from various cardiovascular sources, such as portable ECG monitors, other wearable devices, hospital electronic medical records, biobanks, and non-medical data like activity records, social networks, or email threads.
Xiao et al. (2023)	**Relevant finding:** LBS-TCM was implemented based on Ethereum's open-source code using Golang language. The hardware environment consisted of an Apple computer, with an Intel Core i7 processor, 32GB memory, and 1TB hard drive space. The collected TCM information was then loaded into the LBS-TCM system for testing. The architecture consists of a leading blockchain fragment chain layer as its main component, which employs a sharding mechanism to conveniently track TCM. **Other relevant aspects:** Information on Chinese traditional medicines produced by different manufacturers was collected. For example, product names, main raw materials for production, production company, scale of the production company, business scope of the production company, and place of production. Empirical analysis demonstrated that the architecture outperforms many aspects compared to traditional blockchain architectures, such as TCM transaction processing, TCM transaction inquiry, TCM loading, etc. TCM tracking became an efficient operation, ensuring quality and providing great convenience for subsequent TCM analysis and retrospective research.

REVIEW ARTICLE

Li et al. (2022)	**Relevant finding:** The quality traceability management model of TCM, through blockchain, includes: national macropolicies, TCM laws and regulations, safety traceability management system, safety traceability service platform, safety traceability standardization, governmental supervision and inspection, incentives, and sanction mechanisms. **Other relevant aspects:** Based on the analysis of TCM traceability, combined with the actual needs of Chinese TCM strategic planning, the study seeks to combine and optimize the organizational structure and business functions, control process, and management process, technical support, and TCM supply chain implementation plan. This provides a guarantee to improve the quality of TCM traceability management.
Radanović & Likić (2018)	**Relevant finding:** In the case of private healthcare, it could be used in training and controlling information from institutions, circumstances, and time, as well as the availability of data about healthcare providers. Today, this technology is not ready for a wide spectrum. However, this could change if difficulties are overcome in the coming years, new concepts are developed, use cases, and monetary interests. **Other relevant aspects:** The most relevant advantages of applying this technology in healthcare were analyzed, such as access to a large group of anonymous health services, data that can be used for personalized drug development, streamlining healthcare and medical insurance costs, and improving public health policies.
Siyal et al. (2019)	**Relevant finding:** It was determined that blockchain technology has significant advantages to offer to medicine. Similarly, as the internet revolutionized healthcare and introduced telemedicine, blockchain technology is likely to take medical science to the next level and reduce monitoring costs, with the possibility of having a central server to manage and administer medical data. **Other relevant aspects:** The use of blockchains in clinical contexts will drastically decrease processing time, as soon as a patient enrolls in a study, the data collected will be immediately available, due to availability in the distributed ledger.
Ortiz et al. (2023)	**Relevant finding:** The study allowed for the development of a set of smart contracts describing the processes of the biobank, with the aim of improving the security, integrity, and traceability of samples in biobanks. In this sense, a successful proof of concept was implemented on the IBM blockchain platform, known as Hyperledger Fabric, a private and authorized blockchain.

	Other relevant aspects: Due to its characteristics, blockchain technology is suitable in a biobank environment since it provides: shared, immutable, distributed connection governed by P2P, in which different participants do not have to trust each other, as there is a consensus protocol, ensuring the security and veracity of transactions. Each procedure carried out in a biobank consists of a transaction, and thus, all network participants could validate and know the information of a sample, which cannot be modified due to the immutability provided by blockchain.
Bennacer et al. (2022)	**Relevant finding:** The design of the passport incorporates blockchain technology through a vaccine permit, where nodes are only entities allowed to store vaccination information and verify the QR code scan with the individual's personal information. To interact with the blockchain network, the government node can designate a client node, which can include the ministries of the interior and health. **Other relevant aspects:** This entity also deals with delivering vaccination information to the vaccination center or healthcare professionals. Then, the entity generates vaccination certificates for those who have been vaccinated. These certificates will identify the entity responsible for verifying a person's vaccination status. Information about the vaccine hash value is stored in the network. The registration of these companies will be carried out by the Moroccan government authorities, using smart contracts to present blockchain nodes. Additionally, the blockchain system will contain a hash summary of each person's vaccination certificate, which will be created after registration and used to facilitate the verification process of their vaccination status.
Garrido et al. (2021)	**Relevant finding:** It was determined that the Ethereum protocol is the platform with the best overall performance for the HP-HI. This finding is based on a rigorous analysis of three blockchain protocols: Ethereum, Dogecoin, and Bitcoin, and five criteria for evaluating scalability in BT-based EHR systems: transactions sent, received, failed, and nodes and cost. **Other relevant aspects:** This research was developed to evaluate the implementation of BT-based EHR systems in the context of the Colombian healthcare system.
Liu et al. (2023)	**Relevant finding:** Experimental findings reflect that the P-PBFT consensus algorithm provides smaller latency and higher performance for pharmaceutical traceability systems, supports scalability, effectively alleviates the dramatic increase in communication among network nodes, and reduces the influence of malicious nodes.

Rehman et al. (2022)	**Relevant finding:** The study allowed exploring a secure healthcare 5.0 system, based on blockchain technology intertwined with federated learning techniques to increase predictive performance. The proposed RTS-DELM method has an accuracy rate of 93.22% for disease prediction and 96.18% for intrusion detection. **Other relevant aspects:** It is also emphasized that developing a basic method is more economical and faster. The complexity of the proposed system, from the computing context, is grounded by the increasing number of hidden layers.
Tan et al. (2021)	**Relevant finding:** Over 225,000 retina photographs from nine multi-ethnic cohorts in six regions, obtained with ten different retina cameras, were used, implementing the use of AI in the field of myopia. This is a novel blockchain-based application, considering system design and technique set decision, to workflow management level, integration with existing systems, and toolkit implementation.

DISCUSSION

The evidence in the selected databases related to the application of blockchain technology in medicine reflects the few studies developed in this regard. Indeed, 70 publications were identified, of which 11 were selected that met the inclusion criteria. It was found that all studies were published in nine different English-language journals, and there were publications in each year of the delimited period. Regarding the topics addressed, various applications and characteristics of blockchain technology in medicine stand out. in this regard, the studies by Li et al. [(40)], Xiao et al.[(41)], and Liu et al.[(42)] addressed the application of blockchain technology to design a secure traceability system for managing traditional Chinese medicine and drug production by pharmaceutical companies.

On the other hand, the studies by Siyal et al.[(43)], Radanović & Likić [(44)], Krittanawong et al. [(45)], Tan et al. [(46)], and Garrido et al. [(47)] propose the analysis and design of application proposals based on blockchain technology in the field of medicine, as well as the opportunities and challenges of its integration with other technologies such as AI, to design networks or data storage systems in medicine.

This coincides with the study by Kumar et al.[(1)], who describe various algorithms to solve supervised and unsupervised machine learning problems, combined with deep learning algorithms such as neural networks and different platforms using blockchain technology driven by AI in the field of public health.

It also discusses how AI can improve disease identification and diagnosis, and similarly, blockchain can improve the security of medical records, preserving the privacy of record owners. In the study by Ait et al. [(48)], the construction of a digital medical passport based on blockchain technology is highlighted, aiming to ensure the security and privacy of medical data for Moroccan government entities. Regarding the study by Ortiz et al. [(49)], blockchain is proposed to improve the security, integrity, and traceability of processes executed in a biobank.

Similarly, the study by Azaria et al.[(17)] proposes a system called MedRec, designed as a decentralized medical record management system based on blockchain technology. The system provides patients with a complete and unalterable record, easy access to their medical information, and treatment sites.

Using blockchain characteristics, MedRec manages authentication, confidentiality, accountability, and data exchange, fundamental aspects in managing confidential information. Finally, the study by Rehman et al.(50) evaluated the application of blockchain technology combined with IoMT and federated learning for healthcare 5.0, by building a health monitoring system. These findings coincide with the study by Albakri & Alqahtani(16), who developed a new technique BSHS-EODL for the transmission and analysis of medical images in the IoMT environment, which allows for secure diagnosis and image transmission assisted by blockchain for the IoMT platform. This method includes data classification and collection, as well as image encryption. Likewise, the study by Pava et al.(11) proposes that the application of blockchain in clinical data administration and IoMT medical device management allows the generation of a P6 healthcare model, as it facilitates the management of decentralized patient medical data.

Also, in the study by Ichikawa et al. (18), the incorporation of smartphones into a blockchain-based network for medical data recording is proposed. In this sense, electronic medical records were collected via smartphones and successfully sent to a private Hyperledger Fabric blockchain network. The mHealth application information was updated without network failures. Additionally, it was ensured that all medical information recorded in the blockchain network is resistant to manipulation and review.

The application of blockchain technology in medicine has sparked intense debate about its clinical relevance and its influence on current and future medical practice. According to Siyal et al.(43), the transparency and immutability of medical records in a blockchain can improve diagnosis accuracy and patient monitoring, reduce medical errors, and enhance care coordination. However, Rehman et al. (50) argue that the complexity of implementing this technology, along with concerns about data privacy and security, pose considerable challenges.

The crucial question is whether the potential benefits of blockchain technology, such as data interoperability and traceability, will outweigh the obstacles and translate into real transformation in medical practice or whether this innovation will remain as a promising concept but not fully realized. However, this study has limitations such as the limited number of publications analyzed. It is a brief investigation that, as previously mentioned, was based exclusively on four databases. Additionally, the adoption of this technology in medical environments is still in its early stages, limiting the availability of robust data and use cases for analysis. Also, the complexity of implementing blockchain systems in healthcare infrastructure, along with the need to ensure the security and privacy of patient data, poses a significant challenge. Interoperability between different blockchain-based electronic medical record systems is also a pending issue. Finally, addressing regulatory and ethical concerns related to ownership and access to health information stored on a blockchain is essential.

Future studies could focus on developing specific standards and regulatory frameworks for managing health data in blockchains, thus addressing privacy and security concerns. Additionally, exploring interoperability between electronic medical record systems based on blockchain is needed to ensure effectiveness in clinical practice. Research on integrating smart contracts to automate medical processes and exploring applications in medical research and clinical trials also represent areas of growing interest. In summary, future research in this area has the potential to significantly shape and improve healthcare and health data management in an increasingly digital context.

CONCLUSIONS

In the present systematic review study, the existence of 11 publications related to the research topic was confirmed. Despite considering four databases: Scopus, Web of Sciences, Pro Quest, and ScienceDirect, and a six-year search period (2018 to 2023), the presence of

REVIEW ARTICLE

few investigations based on the application of blockchain technology in medicine was noted. Furthermore, most of the studies in which this technology was implemented aimed to configure a system of integration with other technologies such as AI to build networks or medical records storage systems.

The findings reflect the potential of blockchain technology for the development of data storage systems, data security and privacy in medical data, secure traceability of production, medication control, and its combination with IoMT to develop health monitoring systems. However, the great future potential of this technology in the management of medicine and people's health is envisioned. On the other hand, the study presented certain limitations: only four databases were used, which resulted in a low number of studies comprising the sample; moreover, currently, the application of this technology in the field of medicine is in its early stages; therefore, few analytical cross-sectional studies were found to delve into the findings.

Consequently, it is recommended to conduct primary studies to analyze the implications of adopting blockchain technology in medicine, especially in other contexts that provide feasible solutions for managing and controlling healthcare systems.

Authorship contribution statement: The author participated in the genesis of the idea, project design, data collection and interpretation, results analysis, and manuscript preparation of the present research work.

Funding: Self-funded.

Conflict of interest: The author declares no conflict of interest.

Received: September 04, 2023.
Approved: January 18, 2024.

Correspondence: *Christian Jairo Tinoco Plasencia.*
Address: *Avenida Caminos del Inca 3075, Lima-Perú.*
Telephone number: *978218729*
E-mail: ***christian.tinoco@urp.edu.pe***

REFERENCES

1. Kumar R, Arjunaditya, Singh D, Srinivasan K, Hu YC. AI-Powered Blockchain Technology for Public Health: A Contemporary Review, Open Challenges, and Future Research Directions. Healthcare [Internet]. enero de 2023 [citado 14 de agosto de 2023];11(1):81. Disponible en: https://www.mdpi.com/2227-9032/11/1/81

2. Khezr S, Moniruzzaman M, Yassine A, Benlamri R. Blockchain Technology in Healthcare: A Comprehensive Review and Directions for Future Research. Appl Sci [Internet]. 26 de abril de 2019 [citado 14 de agosto de 2023];9(9):1736. Disponible en: https://www.mdpi.com/2076-3417/9/9/1736

3. Rennock M, Cohn A, Butcher J. Blockchain Tecnology and Regulatory Investigations. ET J. 2018;1(7):35-44.

4.Gaggioli A. Blockchain Technology: Living in a Decentralized Everything. Cyberpsychology Behav Soc Netw [Internet]. enero de 2018 [citado 14 de agosto de 2023];21(1):65-6. Disponible en: https://www.liebertpub.com/doi/10.1089/cyber.2017.29097.csi

5. Palomo R. «Blockchain»: la descentralización del poder y su aplicación en la defensa. Bie3 Bol IEEE [Internet]. 2018 [citado 14 de agosto de 2023];(10):885-904. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=6555546

6. Uchibeke U, Schneider K, Hosseinzadeh S, Deters R. Blockchain Access Control Ecosystem for Big Data Security. En: 2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData). 2018. p. 1373-8.

7.Tucker C, Tapscott D, Iansiti M, Lakhani K. Blockchain: The Insights You Need from Harvard Business Review. Harvard Business Press; 2019. 95 p.

8. Buterin V. A next generation smart contract & decentralized application platform. Ethereum White Pap. 2014;1-36.

9.Fiore M, Capodici A, Rucci P, Bianconi A, Longo G, Ricci M, et al. Blockchain for the Healthcare Supply Chain: A Systematic Literature Review. Appl Sci [Internet]. 4 de enero de 2023 [citado 14 de agosto de 2023];13(2):686. Disponible en: https://www.mdpi.com/2076-3417/13/2/686

10. Saeed H, Malik H, Bashir U, Ahmad A, Riaz S, Ilyas M, et al. Blockchain technology in healthcare: A systematic review. PLOS ONE [Internet]. 11 de abril de 2022 [citado 14 de agosto de 2023];17(4):e0266462. Disponible en: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0266462

11. Pava R, Pérez J, Niño L. Perspectiva para el uso del modelo P6 de atención en salud bajo un escenario soportado en IoT y blockchain. Tecnura [Internet]. 1 de enero de 2021 [citado 14 de agosto de 2023];25(67):112-30. Disponible en: https://revistas.udistrital.edu.co/index.php/Tecnura/article/view/16159

12. Farahat I, Aladrousy W, Elhoseny M, Elmougy S, Tolba A. Improving Healthcare Applications Security Using Blockchain. Electronics [Internet]. 17 de noviembre de 2022 [citado 14 de agosto de 2023];11(22):3786. Disponible en: https://www.mdpi.com/2079-9292/11/22/3786

13. Bit2me Academy. ¿Qué es un hash? [Internet]. 2023 [citado 8 de octubre de 2023]. Disponible en: https://academy.bit2me.com/que-es-hash/

14. Sonkamble R, Bongale A, Phansalkar S, Sharma A, Rajput S. Secure Data Transmission of Electronic Health Records Using Blockchain Technology. Electronics [Internet]. enero de 2023 [citado 14 de agosto de 2023];12(4):1015. Disponible en: https://www.mdpi.com/2079-9292/12/4/1015

15. Mendoza A, Avelar L, García J, Cruz O. Beneficiary Contracts on a Lightweight Blockchain Architecture Using Smart Contracts: A Smart Healthcare System for Medical Records. Appl Sci [Internet]. enero de 2023 [citado 14 de agosto de 2023];13(11):6694. Disponible en: https://www.mdpi.com/2076-3417/13/11/6694

REFERENCES

16. Albakri A, Alqahtani Y. Internet of Medical Things with a Blockchain-Assisted Smart Healthcare System Using Metaheuristics with a Deep Learning Model. Appl Sci [Internet]. enero de 2023 [citado 14 de agosto de 2023];13(10):6108. Disponible en: https://www.mdpi.com/2076-3417/13/10/6108

17. Azaria A, Ekblaw A, Vieira T, Lippman A. MedRec: Using Blockchain for Medical Data Access and Permission Management. En: 2016 2nd International Conference on Open and Big Data (OBD). 2016. p. 25-30.

18. Ichikawa D, Kashiyama M, Ueno T. Tamper-Resistant Mobile Health Using Blockchain Technology. JMIR MHealth UHealth [Internet]. 26 de julio de 2017 [citado 14 de agosto de 2023];5(7):e7938. Disponible en: https://mhealth.jmir.org/2017/7/e111

19. McGhin T, Raymond K, Liu C, El D. Blockchain in healthcare applications: Research challenges and opportunities. J Netw Comput Appl [Internet]. 1 de junio de 2019 [citado 14 de agosto de 2023];135:62-75. Disponible en: https://www.sciencedirect.com/science/article/abs/pii/S1084804519300864

20. Tumi A, Borda J, Tumi E, Torres E, Torres F, Ticona H, et al. Tecnología blockchain para la preservación de registros de historias clínicas médicas. En: Engenharias - Automação, Robótica, Metrologia e Energia: estudos e tendências - Volume 1 [Internet]. 1.a ed. Editora Científica Digital; 2023 [citado 16 de enero de 2024]. p. 66-81. Disponible en: http://www.editoracientifica.com.br/articles/code/230212190

21. Cobeña B. Usos y aplicaciones del Blockchain en el área médica [Internet] [Master tesis]. [Barcelona]: Universitat Politècnica de Catalunya; 2020 [citado 16 de enero de 2024]. Disponible en: https://upcommons.upc.edu/handle/2117/340246

22. Machuca C, Espíritu W. Modelo de Referencia para la Gestión de la Seguridad de Datos de Salud Soportado en una Plataforma Blockchain [Internet] [Pregrado]. [Lima]: Universidad Peruana de Ciencias Aplicadas (UPC); 2021 [citado 16 de enero de 2024]. Disponible en: https://renati.sunedu.gob.pe/handle/sunedu/3093441

23. Hasselgren A, Kralevska K, Gligoroski D, Pedersen SA, Faxvaag A. Blockchain in healthcare and health sciences—A scoping review. Int J Med Inf [Internet]. 1 de febrero de 2020 [citado 16 de enero de 2024];134:104040. Disponible en: https://www.sciencedirect.com/science/article/pii/S138650561930526X

24. Petre A, Haï N. Opportunities and challenges of blockchain technology in the healthcare industry. Med Sci MS. octubre de 2018;34(10):852-6.

25. OECD. Opportunities and Challenges of Blockchain Technologies in Health Care [Internet]. 2020. Disponible en: https://web-archive.oecd.org/2021-05-05/576120-Opportunities-and-Challenges-of-Blockchain-Technologies-in-Health-Care.pdf

26. Salah K, Rehman M, Nizamuddin N, Al-Fuqaha A. Blockchain for AI: Review and Open Research Challenges. IEEE Access [Internet]. 2019 [citado 16 de enero de 2024];7:10127-49. Disponible en: https://ieeexplore.ieee.org/abstract/document/8598784

27. Mellizo D, Minú J. Modelo basado en Blockchain para la implementación de una historia clínica electrónica familiar. Rev Investig En Tecnol Inf RITI [Internet]. 2020 [citado 16 de enero de 2024];8(16):10-22. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=7513585

28. Mora M, Ortiz E. Modelo de Gestión de Historias Médicas, Basado en Tecnología Blockchain, Orientado a la Identificación Automática de Anomalías en las Prescripciones Médicas [Internet]. [Colombia]: Universidad Distrital Francisco José de Caldas; 2018 [citado 16 de enero de 2024]. Disponible en: http://repository.udistrital.edu.co/handle/11349/13641

29. Dunogent A. Tecnología Blockchain: análisis de sus aplicaciones actuales y sus potenciales usos a futuro [Internet] [Tesis]. Universidad Nacional de Luján; 2019 [citado 16 de enero de 2024]. Disponible en: http://ri.unlu.edu.ar/xmlui/handle/rediunlu/831

30. Lluncor A, Almanza L, Huanca V. Modelo Blockchain para prevenir la alteración de informes de reconocimiento médico legal: Caso Instituto de Medicina Legal y Ciencias Forenses [Internet] [Maestría]. [Surco]: Pontificia Universidad Católica del Perú; 2023 [citado 16 de enero de 2024]. Disponible en: https://tesis.pucp.edu.pe/repositorio//handle/20.500.12404/25223

31. Observatorio Blockchain. 2023 [citado 16 de enero de 2024]. 8 Innovaciones Blockchain en el sector Salud - Hypernifty Academy. Disponible en: https://observatorioblockchain.com/hypernifty/blockchain-salud-innovaciones/

32. Arias F. El proyecto de Investigación: Introducción a la Metodología Científica. 6ta ed. Caracas: Episteme; 2012.

33. Mejía E. Metodología de la Investigación Científica [Post grado]. Universidad Nacional Mayor de San Marcos; 2005.

34. Higgins J, Green S. Cochrane Handbook for Systematic Reviews of Interventions. John Wiley&Sons, Ltd., Publication. England; 2008.

35. Moher D, Liberati A, Tetzlaff J, Altman D, for the PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ [Internet]. 21 de julio de 2009 [citado 14 de agosto de 2023];339(jul21 1):b2535-b2535. Disponible en: https://www.bmj.com/lookup/doi/10.1136/bmj.b2535

36. Page M, McKenzie J, Bossuyt P, Boutron I, Hoffmann T, Mulrow C, et al. Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas. Rev Esp Cardiol [Internet]. 1 de septiembre de 2021 [citado 16 de enero de 2024];74(9):790-9. Disponible en: https://www.sciencedirect.com/science/article/pii/S0300893221002748

37. Liberati A, Altman D, Tetzlaff J, Mulrow C, Gøtzsche P, Ioannidis J, et al. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. PLoS Med [Internet]. 21 de julio de 2009 [citado 16 de enero de 2024];6(7):e1000100. Disponible en: https://dx.plos.org/10.1371/journal.pmed.1000100

38.Linares E, Hernández V, Domínguez J, Fernández S, Hevia V, Mayor J, et al. Metodología de una revisión sistemática. Actas Urol Esp [Internet]. 1 de octubre de 2018 [citado 16 de enero de 2024];42(8):499-506. Disponible en: https://www.sciencedirect.com/science/article/pii/S0210480618300615

39. Ciapponi A. La declaración PRISMA 2020: una guía actualizada para reportar revisiones sistemáticas. Evid Actual En Práctica Ambulatoria [Internet]. 4 de agosto de 2021 [citado 14 de agosto de 2023];24(3):e002139-e002139. Disponible en: https://evidencia.org/index.php/Evidencia/article/view/6960

40. Li D, Gong Y, Zhang X, Huang M. An Exploratory Study on the Design and Management Model of Traditional Chinese Medicine Quality Safety Traceability System Based on Blockchain Technology. Secur Commun Netw [Internet]. 1 de junio de 2022 [citado 8 de agosto de 2023];2022:e7011145. Disponible en: https://www.hindawi.com/journals/scn/2022/7011145/

41. Xiao F, Lai T, Guan Y, Hong J, Zhang H, Yang G, et al. Aplicación de la tecnología Blockchain Sharding en el sistema de trazabilidad de la medicina china. Comput Mater Contin [Internet]. 2023 [citado 8 de agosto de 2023];76(1):35-48. Disponible en: https://web.s.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=15462218&AN=164310659&h=4VgNDsPthqelILU1Li2tD1%2fzBEZDgSri0wZlfXL37g7HWyKFlcrVJJWj%2fjg%2bc%2fOWj3MPgWbHoSnPBlIRkCv8%2bw%3d%3d&crl=c&resultNs=AdminWebAuth&resultLocal=ErrCrlNotAuth&crlhashurl=login.aspx%3fdirect%3dtrue%26profile%3dehost%26scope%3dsite%26authtype%3dcrawler%26jrnl%3d15462218%26AN%3d164310659

42. Liu S, Zhang R, Liu C, Shi D. P-PBFT: An improved blockchain algorithm to support large-scale pharmaceutical traceability. Comput Biol Med [Internet]. 1 de marzo de 2023 [citado 8 de agosto de 2023];154:106590. Disponible en: https://www.sciencedirect.com/science/article/pii/S0010482523000550

43. Siyal A, Junejo A, Zawish M, Ahmed K, Khalil A, Soursou G. Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. Cryptography [Internet]. marzo de 2019 [citado 8 de agosto de 2023];3(1):3. Disponible en: https://www.mdpi.com/2410-387X/3/1/3

44. Radanović I, Likić R. Opportunities for Use of Blockchain Technology in Medicine. Appl Health Econ Health Policy [Internet]. 1 de octubre de 2018 [citado 8 de agosto de 2023];16(5):583-90. Disponible en: https://doi.org/10.1007/s40258-018-0412-8

45. Krittanawong C, Rogers A, Aydar M, Choi E, Johnson K, Wang Z, et al. Integrating blockchain technology with artificial intelligence for cardiovascular medicine. Nat Rev Cardiol [Internet]. enero de 2020 [citado 8 de agosto de 2023];17(1):1-3. Disponible en: https://www.nature.com/articles/s41569-019-0294-y

46. Tan T, Anees A, Chen C, Li S, Xu X, Li Z, et al. Retinal photograph-based deep learning algorithms for myopia and a blockchain platform to facilitate artificial intelligence medical research: a retrospective multicohort study. Lancet Digit Health [Internet]. 1 de mayo de 2021 [citado 8 de agosto de 2023];3(5):e317-29. Disponible en: https://www.thelancet.com/journals/landig/article/PIIS2589-7500(21)00055-8/fulltext

47.Garrido A, Ramírez López L, Álvarez N. A simulation-based AHP approach to analyze the scalability of EHR systems using blockchain technology in healthcare institutions. Inform Med Unlocked [Internet]. 1 de enero de 2021 [citado 8 de agosto de 2023];24:100576. Disponible en: https://www.sciencedirect.com/science/article/pii/S2352914821000666

48. Ait S, Aaroud A, Sabiri K, Rguibi M, Cherradi B. Design and implementation of a New Blockchain-based digital health passport: A Moroccan case study. Inform Med Unlocked [Internet]. 1 de enero de 2022 [citado 8 de agosto de 2023];35:101125. Disponible en: https://www.sciencedirect.com/science/article/pii/S2352914822002623

49. Ortiz M, Arias E, Hernández Á, Caminero M, Rojo T, Nam S. Increasing the security and traceability of biological samples in biobanks by blockchain technology. Comput Methods Programs Biomed [Internet]. 1 de abril de 2023 [citado 8 de agosto de 2023];231:107379. Disponible en: https://www.sciencedirect.com/science/article/pii/S0169260723000469

50. Rehman A, Abbas S, Khan M, Ghazal T, Adnan K, Mosavi A. A secure healthcare 5.0 system based on blockchain technology entangled with federated learning technique. Comput Biol Med [Internet]. 1 de noviembre de 2022 [citado 8 de agosto de 2023];150:106019. Disponible en: https://www.sciencedirect.com/science/article/pii/S0010482522007417