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Use of Blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic Review with Bibliometric Analysis

*Maria Guzman Lizama, Jair Huesa, Brian Meneses Claudio**

Facultad de Ingeniería, Universidad Tecnológica del Perú, Lima, Peru

*Correspondence: E-mail: c23363@utp.edu.pe

ABSTRACT

The research questions focused on emerging challenges, solutions, approaches, encryption methods, architectures, and opportunities related to blockchain technology in medical image sharing, and a total of 17 relevant articles were selected from the Scopus database for analysis. The increasing adoption of cloud computing environments in the medical field has raised concerns about security and privacy risks. Within these concerns, problems were identified regarding secure data storage, since centralized storage systems in the cloud mostly lack security effectiveness. Blockchain technology offers a decentralized and secure infrastructure to address these problems. However, a systematic review is needed to identify the strengths and limitations of this technology in this context, therefore the objective of this review is to provide a critical and updated view of the security aspects of the use of blockchain technology in the exchange of medical images in the cloud. The proposed solutions included practical byzantine fault tolerance algorithms, homomorphic encryption, and the integration of smart contracts, among others. In conclusion, this review provides insight into the application of blockchain technology for the secure sharing of medical images in the cloud and identifies key technologies, challenges, solutions, and opportunities in the field.

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1. INTRODUCTION

Clinical information, specifically clinical images, requires treatment that guarantees security in electronic exchange flows. Electronic health records are a way to store patient information and medical images in medical systems and that involves a large number of medical records for each patient (Mohananthini *et al*., 2022; Lepez & Simeoni, 2023; Montes, 2023; Sánchez *et al*., 2022; Benito, 2022). Thus, the availability, integrity, and confidentiality of medical images are important aspects in the large number of applications that include types of images for exchange in real-time (Chhaya and Roopashree, 2023). The increase of digitalization, the adoption of cloud computing environments, and the advances in medical image exchange technologies in medical systems bring challenges regarding security and privacy in the access of unauthorized users or cyber attacks, which easily leak sensitive patient information, for this reason, blockchain technology emerges as a solution to these aspects of security and data privacy (Prasad *et al.*, 2022; Zhang, 2022). However, likely, the blockchain technique is not best suited to provide the necessary information security conditions, therefore a systematic review is required to identify the strengths and limitations of Blockchain technology considering studies to date, and in turn, provide recommendations going forward (Leng *et al*., 2021).

In the absence of previous studies that synthesize the state of knowledge in the addressed area, the need arises to carry out an exhaustive and updated review of the existing literature on security in the exchange of medical images using blockchain technology (Patel, 2019). The main objective of this study was to analyze and synthesize the current state of blockchain technology for the exchange and secure transmission of medical images in the cloud (Inastrilla *et al*., 2023; Canova-Barrios, C., & Machuca-Contreras (2022); Milián, 2023a; Milián, 2023b; Rivas & Cruz, 2022). We also identified and classified solutions and architectures, as well as evaluated simulation environments that use blockchain technology in a cloud computing environment, to provide an organized and updated view of the solutions available in the literature (Fernández & Valencia, 2020; Gontijo *et al*., 2021; Grover *et al*., 2022; Inastrilla, 2022; Ron *et al*., 2023). To support this analysis, we also used bibliometric analysis, which this method is one of the most effective methods for analyzing research trends (Vaishya *et al*., 2023). Detailed previous studies for the use of bibliometrics are presented in **Table 1**.

This review article explores the use of blockchain technology for the secure exchange and transmission of medical images in the cloud. The methodology included a systematic literature review using the PRISMA framework (Ferron, 2021; Hegde *et al*., 2022; Gonzalez-Argote, 2022; Guardado *et al*., 2022; Araujo-Inastrilla & Vitón-Castill, 2023; Montano, 2023). The research questions focused on emerging challenges, solutions, approaches, encryption methods, architectures, and opportunities related to blockchain technology in medical image sharing, and a total of 17 relevant articles were selected from the Scopus database for analysis. The increasing adoption of cloud computing environments in the medical field has raised concerns about security and privacy risks. Within these concerns, problems were identified regarding secure data storage, since centralized storage systems in the cloud mostly lack security effectiveness. Blockchain technology offers a decentralized and secure infrastructure to address these problems. However, a systematic review is needed to identify the strengths and limitations of this technology in this context, therefore the objective of this review is to provide a critical and updated view of the security aspects of the use of blockchain technology in the exchange of medical images in the cloud. The proposed solutions included practical byzantine fault tolerance algorithms, homomorphic encryption, and the integration of smart contracts, among others. Also, the results highlight the potential of blockchain

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technology to improve security and efficiency in the exchange of medical images. In addition, future research opportunities include integrating Blockchain with other cryptographic technologies, developing mobile applications for secure access to medical reports, and improving cloud-based mechanisms. In conclusion, this review provides insight into the application of blockchain technology for the secure sharing of medical images in the cloud and identifies key technologies, challenges, solutions, and opportunities in the field.

Table 1. Previous studies on bibliometric.

No	Title	Ref.
1	Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis	Nandiyanto *et al.* (2023)
2	Bibliometric Computational Mapping Analysis of Trend Metaverse in Education using VOSviewer	Muktiarni *et al.* (2023)
3	The use of information technology and lifestyle: An evaluation of digital technology intervention for improving physical activity and eating behavior	Rahayu *et al.* (2023)
4	Strategies in language education to improve science student understanding during practicum in laboratory: Review and computational bibliometric analysis	Fauziah *et al.* (2021)
5	How language and technology can improve student learning quality in engineering? definition, factors for enhancing students' comprehension, and computational bibliometric analysis	Al Husaeni *et al.* (2022c)
6	Mapping of nanotechnology research in animal science: Scientometric analysis	Kumar (2021)
7	Scientific research trends of flooding stress in plant science and agriculture subject areas (1962-2021)	Nurrahma *et al.* (2023)
8	Introducing ASEAN Journal of Science and Engineering: A bibliometric analysis study	Nandiyanto *et al.* (2023b)
9	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with Covid-19 pandemic condition	Nandiyanto *et al.* (2021)
10	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	Nandiyanto and Al Husaeni (2021)
11	Bibliometric analysis of engineering research using Vosviewer indexed by google scholar	Nandiyanto and Al Husaeni (2022)
12	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	Al Husaeni and Nandiyanto (2022)
13	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	Nandiyanto *et al.* (2023c)
14	Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison with commercial product	Nandiyanto *et al.* (2022d)
15	Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research	Al Husaeni *et al.* (2023a)

2. METHODS

A systematic literature review without meta-analysis has been performed based on the application of the PICO strategy, which helped to develop the search and selection of scientific articles (Pang *et al.*, 2022; Auza-Santiváñez *et al.*, 2023; Telmo, 2021). Detailed information regarding PICO is explained in the following:

(i) P = Exchange and transmission of Medical Images
(ii) I = Blockchain Technology
(iii) C = Guarantee the pillars of information security
(iv) O = Cloud Computing Environment

A strategy was used to pose a structured review question, which was: How has blockchain technology been used to guarantee the pillars of information security in the exchange and transmission of medical images in the cloud computing environment? Based on this question, secondary questions were asked for each PICO component.

In addition, the database called “Scopus” was used, where the words of each of the components were entered to construct the following equation:(TITLE-ABS-KEY ("medical image transmission " OR "medical image" OR "Medical imaging" OR "medical image interchange" OR " medical images exchange" OR " image share" OR " Image sharing" OR "Medical image sharing") AND TITLE-ABS-KEY("Blockchain " OR "blocking" OR "Block-chain" OR "permission blocking" OR "blocking technology") AND TITLE-ABS-KEY (security OR safety OR reliability OR "data security" OR "data-security" OR encryption OR availability OR integrity OR confidentiality OR authentication OR "Computer Security") AND TITLE-ABS-KEY (" Cloud Computing module" OR cloud OR "Cloud computing environment" OR "Cloud storage" OR "Cloud environments" OR "Cloud-computing" OR "Cloud-based" OR "Cloud infrastructures" OR "Cloud server")). An example of the use of bibliometrics is explained elsewhere (Al Husaeni and Nandiyanto, 2022; Azizah *et al*., 2021). As a result of the search, 55 scientific studies were obtained that were reviewed based on the following criteria shown in **Table 2**.

Table 2. Criteria.

Criteria	
Inclusion Criteria	CI1: The article analyzes the use of Blockchain technology.
	CI2: The article analyzes the exchange of medical images.
	CI3: The article discusses the use of cloud medical image storage.
Exclusion Criteria	CE1: Review, Book Chapter, Book and Conference Review.

The studies found in Scopus were selected according to the PRISMA statement (**Figure 1**), which describes the selection process carried out following the criteria of the prism declaration (Singh and Sunitha, 2022). First, 20 scientific studies were eliminated using the first exclusion criterion with the database's automatic filters; 35 studies were recovered to be reviewed based on title and abstract. Secondly, 12 studies were eliminated from the title and abstract review, recovering 23 studies to be reviewed in full text. Third, 4 scientific studies were eliminated because they were not retrieved in full text and 19 articles were retrieved for full text review. Fourthly, applying the evaluation criteria, 2 full-text articles were eliminated. Fifth, 17 articles were selected for inclusion in the SLR. The review question of this research shows in **Table 3**.

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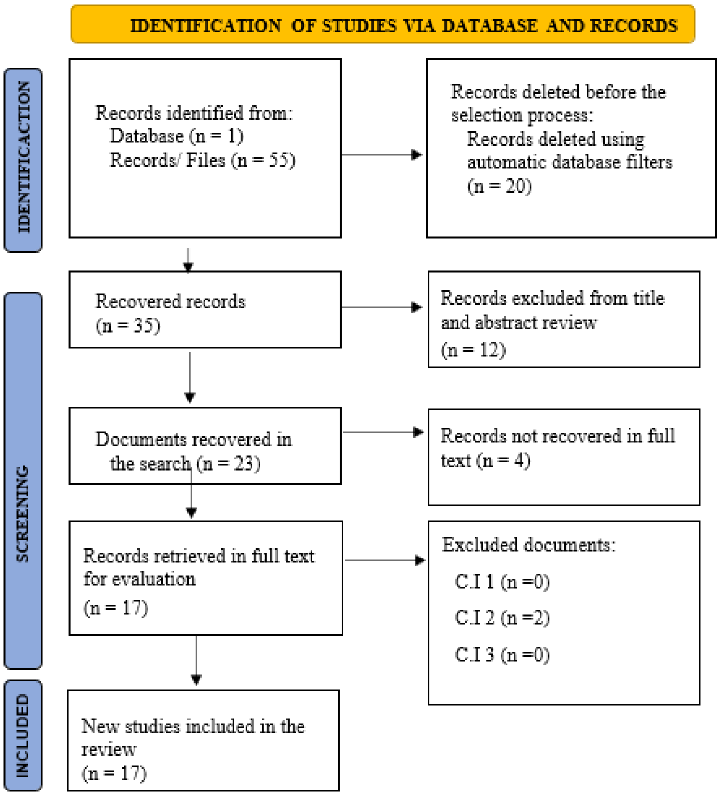

Figure 1. Prism flowchart.

Table 3. Review questions.

No	Research Questions	Description
RQ1	What are the bibliometric data of research articles?	Bibliometric data will be presented (Year of publication, publisher, and country of study center of the main author).
RQ2	What are the problems found in the research articles before proposing a solution proposal?	The problems encountered will be described before proposing a solution for the exchange of medical images.
RQ3	What is the focus of blockchain technology in research articles?	The blockchain approach will be described in the article
RQ4	What encryption proposals are used in scientific articles?	The name of the encryption proposal and the compared methods will be presented.
RQ5	What type of architectures do the research articles propose?	The type of architecture presented will be presented.
RQ6	What environments and what data were simulated to evaluate the proposals?	• The characteristics of the simulation environment will be presented. • The data type and the simulated quantity will be presented.
RQ7	What technologies participate in research articles?	The technologies used in the proposal will be presented.
RQ8	What metrics did the articles apply to evaluate their effectiveness?	The metrics used by the scientific articles will be presented.
RQ9	What results were obtained after applying the metrics?	The results of the metrics of the scientific articles will be presented.
RQ10	What security properties do the proposed solutions have?	Security properties that the articles have will be presented.
RQ11	What are the opportunities and new applications identified?	The opportunities and new applications identified will be presented.

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3. RESULTS AND DISCUSSION

3.1. RQ1: What are the Bibliometric Data of the Reviewed Articles?

Depending on the results of the review, the articles are published in different channels. **Figure 2** shows the publishers where the articles were published. The number of articles is 17, and the one with the highest number of published articles is IEEE with 35.2% (n=6), then there is Springer with 29.4% (n=5). The remaining articles were published in publishers such as Tech Science Press (n=1), SAI (n=1), MDPI (n=3), Hindawi Limited (n=1), and Elsevier (n=1).

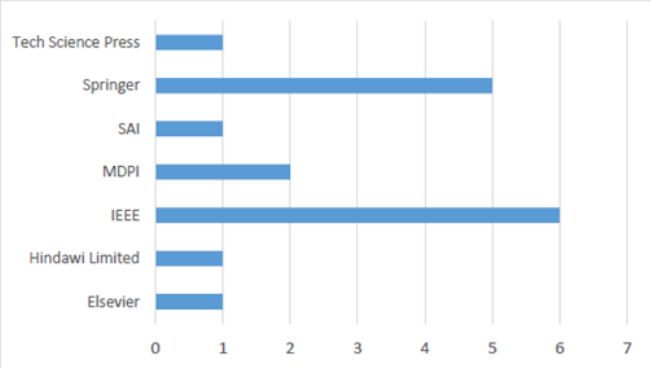

Figure 2. Count by publisher name.

The year with the highest number of articles published is 2023 (n=8), 2022 (n=5), 2021 (n=3) and 2020 (n=1). These quantities indicate a progressive growth year after year in research on blockchain technology for the exchange and secure transmission of medical images in the cloud. It is important to note the count of countries of institutions of the main authors of the articles in the context of the review, as it provides a clear view of the diversity and geographical scope of the research carried out on the topic. In addition, the countries identified are 6 and for this reason, the study was carried out by country and not by continent. The countries with the highest participation regarding universities in research articles are China and India with 35%, followed by Saudi Arabia and South Korea with 11%.

3.2. RQ2: What are the Problems Found in the Research Articles Before Proposing a Solution Proposal?

The use of blockchain technology for the exchange and secure transmission of medical images in the cloud poses various challenges in the health field. In the literature, problems were identified and solutions were proposed to address them. Among the problems encountered, we identified the secure storage of medical data, especially medical images. Also, centralized cloud storage systems lack sufficient security, which raises concerns about privacy protection and prevention of unauthenticated access (Calcagno, 2023). Among the solutions, we have: is the proposal of a consensus algorithm called Practical Byzantine Fault Tolerance (PBFT) to improve the efficiency and manageability of a Blockchain-based system. Furthermore, the proposal is to use blockchain-based homomorphic encryption to ensure secure communication of medical images (Padrón, 2023; Parra *et al.*, 2023).

3.3. RQ3: What is the Focus of Blockchain Technology in Research Articles?

After a rigorous analysis of the scientific documents, we identified different perspectives that converge towards the same objective, which is the security in the exchange and transmission of medical images. **Figure 3** shows the different approaches that blockchain technology can have in the proposals of scientific articles. The approach with the greatest

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participation is the use of blockchain technology to distribute storage in a decentralized manner, followed by safeguarding against alteration of data that is in 10 scientific articles. Likewise, 9 scientific articles focused on preventing falsification, 8 scientific articles focused on the secure transfer of data, 6 scientific articles focused on data authentication validity, 5 scientific articles focused only on the sharing of information, and 4 scientific articles focused on access permission management. Also, there are different approaches with less involvement such as gaining access to medical imaging data, generation of non-modifiable records, simplifying the recovery of encrypted images, and management of large amounts of data.

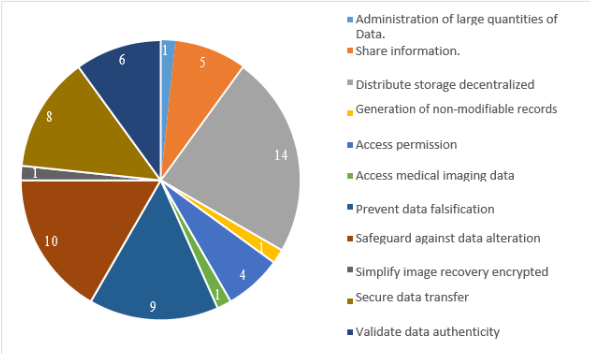

Figure 3. Count of blockchain technology approaches.

3.4. RQ4: What Encryption Proposals are used in Research Articles?

After an exhaustive review of scientific articles, we found different encryption proposals for the secure exchange and transmission of medical images in the cloud computing environment. **Figure 4** shows the count of standardized encryption proposals and indicates that the cryptographic technique was used by 4 scientific papers. Furthermore, 3 scientific articles did not apply encryption in their proposal, however, the cryptographic hash function and encryption scheme were found in 3 scientific articles for the security of medical images. The least used are encryption techniques, symmetric encryption algorithms, cryptographic algorithms, and cryptography standards. Likewise, a comparison was made with other encryption proposals to corroborate their effectiveness.

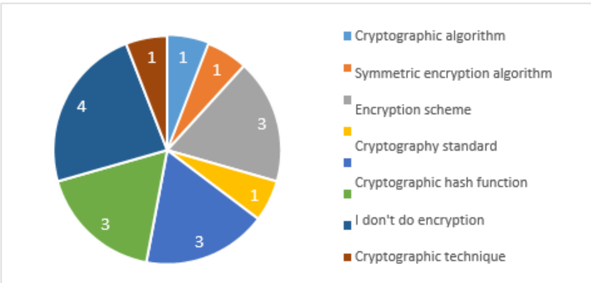

Figure 4. Standardized encryption proposal count.

3.5. RQ5: What Kind of Architectures do the Research Articles Propose?

After an arduous review of the scientific articles, **Figure 5** shows the count of architecture types. We observed that one of the scientific articles had a unified type architecture, while 14 scientific articles had a type of decentralized architecture for the deployment of the proposal for secure exchange and transmission of medical images in the cloud environment. However, 4 scientific articles do not mention what type of architecture was used.

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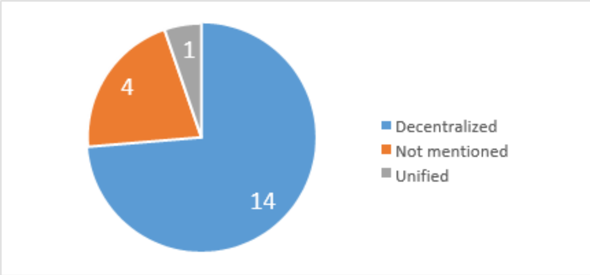

Figure 5. Architecture type count.

3.6. RQ6: What Environments and Data Were Simulated to Evaluate the Proposals?

The datasets that were used in the studies were varied according to the type of images (see **Figure 6**), including X-ray, magnetic resonance, computed tomography, ultrasound, color and black and white fundus, and image annotations, used to evaluate the proposals related to blockchain technology in the exchange and secure transmission of medical images in the cloud. Among the characteristics of the devices that were used to perform simulations in the research articles, we have the following: First, in **Figure 7**, the operating systems used included Windows 10, Ubuntu 18.04 and 16.04, CentOS 6.5 and 7, and Linux. **Figure 8**, the RAM capacity varied such as 4, 8, 16, and 32 GB. **Figure 9**, the CPUs used included Intel core i5, Intel core i7, AMD EPYC 7H12. On the one hand, some studies did not provide detailed information about the simulation environment. On the other hand, some studies used more than one machine to perform simulations.

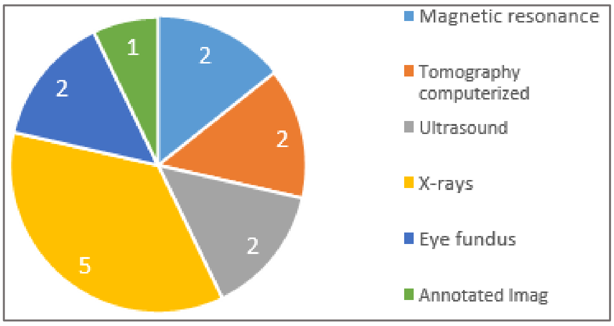

Figure 6. Type of images.

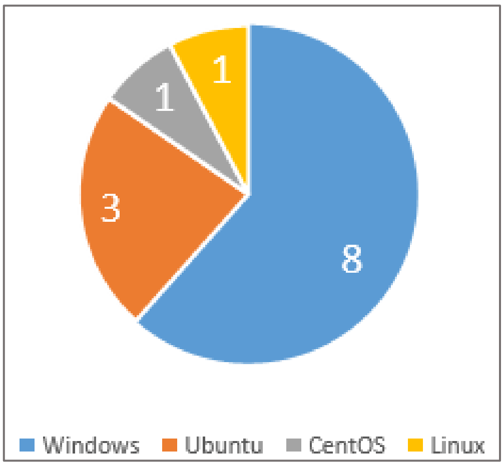

Figure 7. Operating systems

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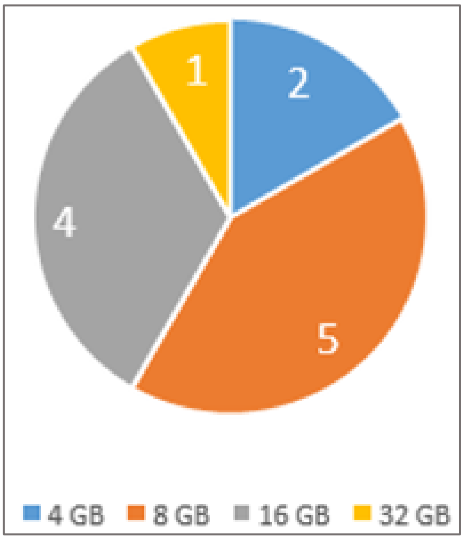

Figure 8. RAM memories.

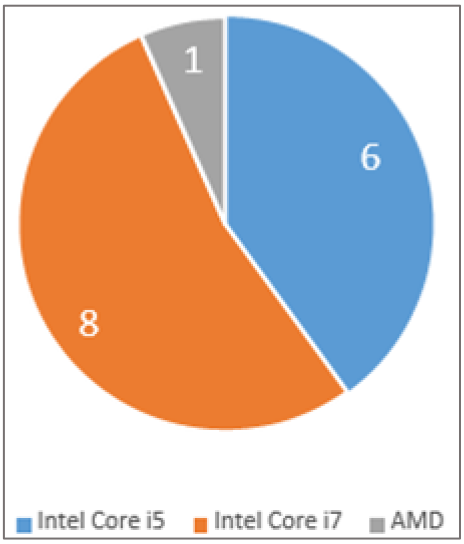

Figure 9. CPU type.

3.7. RQ7: What Technologies Participate in the Research Articles?

The participation of technologies (see **Figure 10**) in research articles on the use of blockchain technology for the exchange and secure transmission of medical images in the cloud highlights the participation of technologies such as fog computing as part of a secure electronic medical records system based on blockchain technology, IPFS is mentioned in several articles as a solution for storing and distributing medical images in a decentralized and secure environment, smart contracts are used in multiple studies to establish specific rules and conditions related to access and secure exchange of medical images, providing high-level security and automation, IoT is mentioned in some articles concerning the integration of medical devices and sensors for the collection of medical data and its subsequent secure storage and transmission using blockchain technology.

However, blockchain technology is used in all the articles collected and is used to ensure the security, integrity, and privacy of shared medical images. Also, the cloud environment is widely used in studies as a platform for sharing and storing medical images.

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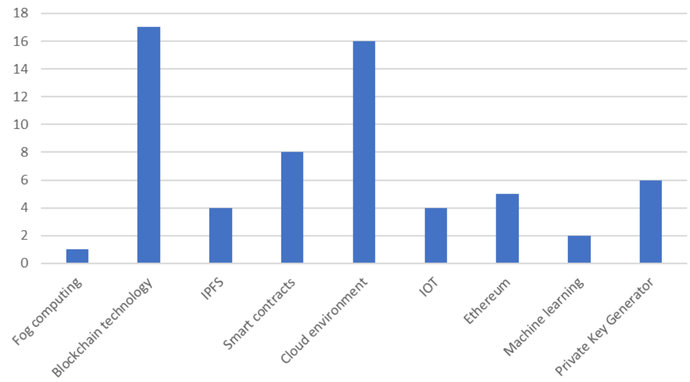

Figure 10. Participating technologies.

3.8. RQ8: What Metrics Did the Articles Apply to Evaluate Their Effectiveness?

Table 4 shows the different types of evaluation metrics that the scientific articles applied to test their effectiveness. The computational cost is expressed in kilobytes (KB) and milliseconds (ms) and is in 5 articles. Also, 3 scientific papers have the image quality metric MSE (Mean Squared Error) readings, 2 scientific papers present the image quality metric PSNR (Pixel Number Change Rate) readings, 6 scientific papers have the encryption time, 5 scientific papers have the decryption time and 4 scientific papers present the gas price for medical image exchange.

Table 4. Evaluation metrics.

Authors	Metrics
Jaya Singh and Jagatheeswari (2023)	Communication cost (KB - ms); Authentication accuracy
Salim and Park (2023)	Comparison of loading time for X-Ray and PDF files. Comparison of download time of X-Ray and PDF files. Loading time to load the IPFS hash address and the EHR recording blockchain.
Neela and Kavitha (2023)	Entropy results for various methods Unified Average Change Intensity (UACI) Number of Pixel Change Rate (NPCR) Structural Similarity Index (SSIM) Mean Square Error (MSE) Normalized Correlation Analysis (NC)
Peng *et al*. (2023) Chen *et al*. (2023)	Communication overhead (ms - bits) Store indexes Save query token Hash verification Index update Contract Cost Evaluation
Peng *et al*. (2023) Chen *et al*. (2023)	Communication overhead (ms - bits) Store indexes Save query token Hash verification Index update Contract Cost Evaluation
Qamar (2023)	Comparative analysis between the proposed technique and the existing one for classification Comparative analysis between the proposed method and the existing one for Network security

Table 4 (continue). Evaluation metrics.

Authors	Metrics
Mahajan and Junnarkar (2023)	Analysis of encryption time using test medical images Analysis of decryption time using test medical images PSNR analysis using medical test images MSE analysis using medical test images Average performance analysis using PCXRA data set Average performance analysis using CCSC data set
Chhaya and Roopashree (2023)	Time for data repositioning Data recovery time The operating cost Comparison with conventional blockchain method
Mohsan *et al.* (2022)	Smart contract execution cost analysis (gas cost = 2 Gwei). The computational time for executing the function to access IPFS and Blockchain data
Hegde *et al.* (2022)	Storage time to store 10,000 records. Access Time to access 10,000 records. Price of gas consumed when uploading data to the blockchain. Average storage and access time of STORJ, IPFS and COSMOSDB Prediction result as CKD Prediction result as NOCKD Prediction time
Pang *et al.* (2022)	The fault-tolerant ability of sc-PBFT and PBFT. Comparison between different models. TPS test without Byzantine node. TPS test with a Byzantine node Consensus. Latency with and without Byzantine node.
Prasad *et al.* (2022)	Parameters of the data cleaning model. Comparison of role-based access control. Comparison of time consumption. (a) Encryption and decryption. (b) Signature and authentication
Almasoud *et al.* (2022)	Data set description. Analysis results of the identification data set for the proposed FDNN method. Accuy analysis results of the FDNN approach Viewing the MSC model Results of the comparative study of Inceptionv3 + OWNN against state-of-the-art methods
Alzubi (2021)	Performance comparison based on communication overhead (KB) Performance comparison based on data delivery rate (%) Performance comparison based on data confidentiality rate (%) Performance comparison based on data integrity rate (%) Performance comparison based on privacy preservation rate (%).
Jabarulla and Lee (2020)	**Table 1** PCAC-SC Cost Analysis Comparison between the Current and Proposed PCIM System.
Zhang *et al.* (2019)	Comparison of communication overheads TPA Audit Cost Comparison User Verification Cost Comparison
Zhang *et al.* (2020)	Time comparison

3.9. RQ9: What Results were Obtained After Applying the Metrics?

We have extracted the results of different metrics with different amounts of simulated data (**Table 5**). First, the computational cost was 16 KB for 800 medical data. Second, the Pixel number change rate (PNSR) image quality metric reading for a test image was 49.64 image quality. Third, the normalized correlation (NC) analysis was 0.987 frames per second. Fourth, the reading of the image quality metric Mean Squared Error (MSE) presented three different types of images, such as Magnetic Resonance Imaging (MRI), which generated 75 image quality, then Computed Tomography (CT) which generated 81 image quality and X-ray which generated 78 image quality. Also, the shortest encryption time was 15 ms, while the shortest decryption time was 40 ms. However, 4 scientific papers presented different processes and price proposals when showing the gas price.

Table 5. Metric results matrix.

Authors	Computing cost	PSNR image quality metric readings	MSE Image Quality Metric Readings	Encryption time	Decryption Time	Gas Price
Jaya Singh and Jagatheeswari (2023)	150 images: 15.35ms 150 images: 105.25 KB	-	-	-	-	-
Peng, Zhang and Lin (2023)	Case1 11032 bits Hospital A: 32.335ms Doctor B: 19.916ms Patient C: 9.796ms Case2: 6440 bits Hospital A: 17.448ms Doctor B: 8.682ms Patient C: 5.898ms	-	-	-	-	-
Chen *et al.* (2023)	-	-	-	-	-	Implement: 150516 GWei Load Indexes: 1430617GWei Authorization: 177600GWei Recovery: 5908513GWei
Qamar (2023)	-	MRI: 79 CT: 75 X-Ray: 77	MRI: 75 CT: 81 X-Ray: 78	MRI: 59 ms CT: 56 ms X-Ray: 63 ms	MRI: 55 ms CT: 55 ms X-Ray: 61 ms	-

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Table 5 (Continue). Metric results matrix.

Authors	Computing cost	PSNR image quality metric readings	MSE Image Quality Metric Readings	Encryption time	Decryption Time	Gas Price
Mahajan and Junnarkar (2023)	-	1 image test: 49.64	1 image test: 501.8	1 image test: 12.45 seg	1 image test: 8.3 seg	-
Chhaya and Roopashree (2023)	34.8% reduction in operating cost	-	-	-	-	-
Mohsan *et al.* (2022)	10 medical images: 145ms 10 Blood/Lipid reports: 37ms	-	-	12.46 seg	8.3 seg	Contract creation: 2869227GWei Contract Starts: 225237GWei Initial Migration Call: 42363GWei Migration Contract Call: 27363GWei
Hegde *et al.* (2022)	-	-	-	-	-	0.00066888ETH (Ether) de gas (Ether)
Pang *et al.* (2022)	-	-	-	-	-	-
Prasad *et al.* (2022)	-	-	-	15ms	40ms	-
Almasoud *et al.* (2022)	-	-	-	-	-	-
Alzubi (2021)	Subject 10: 19KB	-	-	-	-	-
Jabarulla and Lee (2020)	-	-	-	-	-	create_contract(): 67.394GWei request_access(): 246.908GWei approve_IR(): 170.412GWei track_authorization(): 34.266GWei remove_IRs(): 59.358GWei
Zhang *et al.* (2019)	800 medical data: 16KB	-	-	-	-	-
Zhang *et al.* (2020)	-	-	-	32ms	-	-

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3.10. RQ10: What Security Properties do the Proposed Solutions Have?

Table 6 shows the names of the properties of a "✓" if the property exists within the proposal and an "X" if the property does not exist. Likewise, we evaluate 8 different properties, which we have found in the proposals of the scientific articles to demonstrate effectiveness, these proposals are: Confidentiality, Integrity, Availability, Authentication, Verifiability, Interoperability, Efficiency, and Scalability. Most scientific articles focusing on the secure exchange and transmission of medical images contain confidentiality as the main property, followed by authentication. Availability and interoperability are the properties that we could find the least within the proposals. This shows that blockchain technology is very difficult to be interoperable with other systems.

Table 6. Metric results matrix.

Authors	Confidentiality	Integrity	Availability	Authentication	Interoperability	Efficiency	Scalability
Jaya Singh and Jagatheeswari (2023)	✓	X	X	✓	✓	X	X
Salim and Park (2023)	✓	✓	X	✓	X	X	X
Neela and Kavitha (2023)	✓	X	✓	✓	X	✓	✓
Peng, Zhang and Lin (2023)	✓	✓	X	✓	✓	✓	X
Chen *et al.* (2023)	✓	✓	X	✓	X	✓	X
Qamar (2023)	✓	✓	X	✓	✓	X	X
Mahajan and Junnarkar (2023)	✓	✓	X	✓	X	✓	✓
Chhaya and Roopashree (2023)	✓	✓	X	✓	X	✓	X
Mohsan *et al.* (2022)	X	✓	X	X	X	✓	X
Hegde *et al.* (2022)	✓	✓	✓	✓	X	✓	✓
Pang *et al.* (2022)	✓	X	X	✓	✓	✓	✓
Prasad *et al.* (2022)	✓	✓	X	X	✓	✓	✓
Almasoud *et al.* (2022)	✓	✓	X	✓	X	✓	✓
Alzubi (2021)	X	X	X	✓	X	✓	✓
Jabarulla and Lee (2020)	✓	✓	X	✓	✓	✓	X
Zhang *et al.* (2019)	✓	✓	X	✓	X	✓	✓
Zhang *et al.* (2020)	✓	✓	X	✓	X	✓	X

3.11. RQ11: What are the Opportunities and New Applications Identified from the Use of Blockchain Technology in the Exchange, Transmission, and Sharing of Medical Images in the Cloud Computing Environment?

Several studies highlight that blockchain technology offers significant improvements in the security and efficiency of the exchange of sensitive medical images as mentioned by Pang *et*

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al. (2022), from research question number 7, although it is not the main focus of the research articles, machine learning is mentioned in some articles by Hegde *et al*. (2022), and Qamar (2023) and they consider that it is a complementary technology to improve the early detection of diseases and the collaborative analysis of medical images, therefore, there would be a notable improvement in medical care. Furthermore, it is proposed to develop a smart mobile application that allows patients and doctors to securely access medical reports, thus improving accessibility and efficiency, and it is also proposed to integrate the Ethereum blockchain with other cryptographic technologies to improve cloud-based mechanisms for improving its performance, security, and functionality. Future research and improvements in the use of Blockchain with different technologies are promising and have the potential to significantly improve the quality of healthcare and data security.

3.12. Discussion

In this review study, a total of 17 scientific articles published in the four years that investigate the use of blockchain technology for the exchange and secure transmission of medical images in the cloud have been reviewed. The bibliometric data of the articles revealed a growing trend of interest in this emerging technology (Aguirre *et al*., 2020; Nahi *et al*., 2023; Ron & Escalona, 2023). Furthermore, the scientific articles come from a variety of countries, indicating that blockchain technology has generated significant interest internationally. The countries from which the largest number of articles were obtained were China and India, the data indicates that these countries that belong to the continent Asians have a greater interest in investigating and adopting blockchain technology in their cybersecurity proposals.

During the analysis of the articles, different common problems were identified before proposing a solution proposal. One of the main problems found was the lack of security in the storage and exchange of medical images, which creates an urgent need to develop and adopt a technology such as blockchain that offers advanced cryptographic features and decentralized storage.

Regarding the approach to blockchain technology in the scientific articles reviewed, a wide variety of applications was identified. Most of the articles focused on using Blockchain to distribute storage in a decentralized manner and safeguard information against data tampering. These findings demonstrate the effectiveness of blockchain technology in various areas, suggesting its potential as a proposed solution to reliably protect and secure data.

Concerning the encryption proposals used in the scientific articles, various forms of encryption were used. However, a difficulty in unifying these proposals was identified due to the differences in the cryptographic approaches and algorithms used in each study. For example, Jaya Singh and Jagatheeswari (2023) proposed the Lamport Merkle encryption technique, which consists of building a Merkle tree from the Lamport private keys and the root of the tree is signed, unlike Mahajan and Junnarkar (2023), who proposed an Elliptic Curve Cryptography (ECC) technique that consists of constructing an encryption and decryption security key using the Elliptic Curve Differ-Hellman (ECDH) technique and different from Hegde *et al*. (2022), who proposed the encryption algorithm AES-256-GCM Encryption which consists of symmetric encryption that uses a 256-bit key to encrypt and decrypt data.

Two different types of proposed architectures were identified in the scientific papers. Most of the papers proposed to use the decentralized type of architecture, while Mahajan and Junnarkar (2023) proposed a unified architecture, which they highlighted as a revolutionary approach in their study.

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In terms of simulated environments and data to evaluate the effectiveness of the proposals, all the proposals in the scientific articles proposed different sets of data, quantities, and types of images, which made it difficult to make a comparison. Likewise, a greater amount of information was collected regarding simulation environments, such as the name of the operating system, the capacity of the RAM memory, and the characteristics of the CPU.

At the same time, we found a variety of technologies that participated in scientific articles to ensure the exchange of medical images, such as fog computing, IPFS, smart contracts, cloud environment, IoT, Ethereum, machine learning, and private key generators.

Regarding the metrics applied to evaluate the effectiveness of the proposals, the articles used different types of metrics, which made it unlikely to find an accurate answer when making a comparison of results. Likewise, a table of results is shown with very little data and with different measurement indicators. For example, Neela and Kavitha (2023) proposed encryption using Chaotic Deep GAN Encryption that showed that their network can encrypt or decrypt 14.31 medical images per second at a resolution of 256 × 256, while images with a resolution of 512 × 512 can be encrypted or decrypted at 4 images per second, compared to Qamar (2023), who used a Lorenz chaotic encryption with three different types of images, such as MRI, CT and X-Ray, and their times were consecutively the following: the encryption time was 59 ms, while the decryption time was 55 ms; encryption time 56ms, while decryption time 55ms; the encryption time of 63 ms, while the decryption time of 61 ms. Similarly, Prasad *et al*. (2022) used a BL-CL-PKC (Blockchain-Based Certificateless Public Key Cryptography) resulting in an encryption time of 15 ms and a decryption time of 40 ms. In summary, 3 different ways of encrypting were discussed with different results, but with the same purpose, which is to apply an encryption and decryption method for the secure exchange and transmission of medical images in the cloud.

Regarding the security properties of the solutions proposed in the scientific articles, 8 properties were found, 4 of them were focused on security, and the rest on the system. Also, confidentiality and authentication are the properties that are within the scientific articles, while availability is the property that was least tested after proposing a proposal architecture because it involves keeping data and services accessible, operational, and functioning correctly for authorized users, which is essential to ensure a reliable system when transmitting data.

Finally, regarding the opportunities and new applications identified in the scientific articles, several scientific articles suggested the use of blockchain in emerging fields. This proposal consists of integrating Ethereum blockchain technology with other cryptographic technologies to enhance cloud-based mechanisms and thus improve its performance, security, and functionality. This combination of technologies promises a promising future since research and improvements in the use of blockchain together with different technologies have the potential to significantly raise the quality of healthcare and data security.

Different encryption proposals were presented, such as cryptographic algorithms, symmetric encryption algorithms, encryption schemes, a cryptography standard, cryptographic hash functions, and proposals that did not use encryption for security. Similarly, the use of decentralized architecture was identified in most of the scientific articles.

In the same way, the data used in the simulation environment was identified, such as the type of images, including X-ray, magnetic resonance imaging, computed tomography, ultrasound, color and black and white fundus, and image annotations. Along the same lines, the simulation environments were recognized, as the most used operating system is Windows, the maximum capacity of random access memory (RAM) is 32 GB, while the

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minimum RAM capacity is 4GB. Likewise, the best central processing unit (CPU) is the Intel Core i7 10700, a scientific article uses the RTX3090 graphics processing unit (GPU), the 128 GB SSD (Solid State Unit), and the 1TB HDD (Hard Drive) and some articles used more than one simulation environment.

In addition, different technologies that participate in the research articles were identified such as fog computing, IPFS, smart contracts, IoT, and cloud computing, which are key technologies that are used together with blockchain to improve security and efficiency in the exchange of medical images.

4. CONCLUSION

Various encryption methods, including cryptographic algorithms and symmetric encryption, were discussed, along with a focus on decentralized architecture in most scientific articles. The data used in simulations encompassed various image types like X-ray, MRI, CT scans, ultrasound, and fundus images, along with their annotations. Simulation environments primarily ran on Windows OS, with RAM ranging from 4 to 32GB, featuring Intel Core i7 10700 CPUs, RTX3090 GPUs, 128GB SSDs, and 1TB HDDs in some cases. Additionally, articles explored technologies like fog computing, IPFS, smart contracts, IoT, and cloud computing, in conjunction with blockchain, for enhancing medical image security and efficiency.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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