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Retraction

Retracted: Systematic Assessment of the Interoperability Requirements and Challenges of Secure Blockchain-Based Electronic Health Records

Security and Communication Networks

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] F. A. Reegu, H. Abas, Z. Hakami et al., "Systematic Assessment of the Interoperability Requirements and Challenges of Secure Blockchain-Based Electronic Health Records," *Security and Communication Networks*, vol. 2022, Article ID 1953723, 12 pages, 2022.

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Research Article

Systematic Assessment of the Interoperability Requirements and Challenges of Secure Blockchain-Based Electronic Health Records

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A peer-to-peer (P2P) decentralized information-sharing network is used to share data and maintain security, privacy, and integrity standards called blockchain. In this case, information sharing and updating require regular simplification. The presented systematic review mainly focuses on the interoperability of electronic health records (EHRs) using blockchain. Correspondingly, 18 blockchain-based solutions were selected to address the interoperability challenges of EHRs. The limitation of solutions includes reliability, privacy, integrity, sharing, and standards. This systematic review contains six phase's research question, research phase, article selection, abstract-based keyword, data extraction, and progress tracking. Various Web resources such as Google Scholar, Web of Science, and IEEE are used to extract the relevant manuscripts. Primarily, 18 articles were selected to present the interoperable requirements of EHRs using blockchain, standards of blockchain-based EHRs, and solutions for interoperability of EHRs using blockchain. The conducted study explains the best available interoperable blockchain-based EHR standards, implementations, applications, and challenges.

1. Introduction

Blockchain is a decentralized, fast, secure, and private technology used to exchange information. Blockchain technology can transform the traditional healthcare system by maintaining patient data privacy and security [1]. Blockchain has the power to change the way patients' electronic health records are transferred and stored by providing safer ways for medical information transfer in the healthcare industry and securing it via a randomized peer-to-peer network [2, 3]. The implementation of technology makes electronic health records (EHRs) robust and secure [4]. Blockchain technology has the potential to improve health care by putting the individual at the center of the health system and promote health data security, transparency, and interoperability. By making electronic health records (EHRs) more efficient and secure, this technology might create a new paradigm for interoperability (HIE) [5, 6]. The EHR system contains the sensitive information of patients, including diagnostics and treatment. The patient data are an asset for the healthcare system. The collection and distribution of healthcare data are essential sources to analyze the healthcare system's ability to provide healthcare services [7]. EHR includes critical and very sensitive private information for medical diagnosis and treatment. These databases are a valuable source of patient information. The sharing of healthcare data is an essential step in making the national healthcare intelligent and improving service quality

[8, 9]. A structural and well-formatted patient health data are maintained and stored at various hospitals, clinics, and the government, and healthcare department is an EHR [10].

Interoperability in an EHR plays a key role, and it refers to the ease with which medical records and healthcare information may be shared from one provider or system to another. While healthcare systems can communicate in a variety of ways, the EHR is widely recognized as one of the simplest and most secure alternatives that do not result in data blockage. By concentrating on EHR interoperability and developing ways to improve it, healthcare systems may smooth out frequent communication channels, increase overall patient contentment, and even reduce common healthcare expenses. An electronic health record (EHR) is a digitally recorded structure of a patient's health data that is produced and managed over the course of the patient's life. It can often be stored and provided by various hospitals and clinics, including health professionals [11, 12]. The semantic interpretability concept of EHR [13] has several challenges. Security is the biggest challenge, and electronic healthcare systems are the primary prey of cyberattacks. According to research, one-third of all cyberattack victims were healthcare systems [14]. Blockchain, which supports a sharing and trust mechanism, might be a future option for data sharing, allowing for collective healthcare decision in telehealth and precision medicine [15, 16]. Ransomware 88% of attack victims were healthcare systems. Data of 80 million people are breached during the attack of 4 February 2015 called anthem breach attack. Another challenge is the size of the EHR database, which is increasing rapidly. The patient data [17] include patient information and X-rays, and computed tomography, which has a large size and requires ample storage space. In 2015, an average healthcare system had storage space of 665 terabytes, which increased to 25,000 petabytes in 2020. The main occupants of storage space are medical images in the unstructured form [18]. Another challenge is the heterogeneity of healthcare systems. Various health service providers used their database management system, different system architecture, and data infrastructures [19]. Data integrity and standardization are becoming challenging and prominent among cross-health service providers. The heterogeneity of health service providers makes it challenging to share precise and standardized data for useful applications. The study covers the following:

(i) Importance of interoperability of EHR using blockchain technology

(ii) Challenges of implementing blockchain technology in EHR systems

(iii) The requirement of an interoperable blockchain-based system

(iv) A summary of interoperable EHR requirements, problems, and solutions

The article has six sections. Section 2 elaborates on the relevant work on blockchain and its usage in the healthcare system. Section 3 enlightens the research methodology and step adopted for this systematic review followed by Section 4 that presents research question-based results. Section 5 presents requirements, standards, and solution. The article conclusion is presented in Section 6 followed by future directions.

2. Related Work

2.1. Blockchain. A peer-to-peer (P2P) ledger-based distributed technology used for Web-based information sharing is called blockchain and was initially invented for the financial sector for transactions by skipping the role of arbitrator. It is the same as the mediator in government and private organizations who play a trusted third party (TTP) to receive and process transactions. TTP is not valid and trustworthy because it can be malfunctioning, or a security breach can affect the whole transaction system [20]. The extensive use of electronic health records (EHRs) improves the efficiency and adaptability of medical services. It has the potential to dramatically improve the convenience, intelligence, and accuracy of public healthcare treatment, particularly when combined with cloud storage and mobile apps. Because of its centralized management, EHRs are more vulnerable to centralized assault, purposeful manipulation, and single-point failure. It suggests that protecting patient privacy and other sensitive data will become more difficult, leading to more frequent conflicts between doctors and patients [21, 22]. Technically, blockchain is a decentralized database presented over a P2P network. A typical blockchain contains nodes, contracts, and blocks. The information is stored on a block, and the nodes are the point of connection between the blockchain members. In the blockchain environment, every node contains a copy of local data called a block. When the nodes agree on a contract, the transaction is performed and has validity [23].

2.2. Use of Blockchain in Electronic Health Records (EHRs). Blockchain-based application robustness has provided decent support in the medical industry and medical support systems. Various applications are presented in the literature review for maintaining EHRs by taking into consideration the factor interoperability. Interoperability of EHR enables the health service providers to update a patient's record over the synchronized blockchain network [24]. The EHR using blockchain is a new era system that monitors patient health and records patients' treatments, surgeries, and therapies' schedule.

Interoperable EHRs simplify the insurance system by processing the health insurance claims and updating the payment system authentications. Blockchain in EHRs enables researchers and biomedical scientists to utilize the health data to estimate statistical analysis and create robust diagnostic applications and medicines. The importance of blockchain is presented using research reviews, applications, and unique security solutions for problems.

Interoperability, scalability, and cross-platform implementation are challenges in the blockchain-based application in the area of health care. A distributed healthcare system that removes the central mediator creates a serious abrupt in the standard healthcare systems [25].

3. Research Methodology

The systematic research contains six primary tasks such as (1) research question, (2) research steps, (3) suitable article selection, (4) keywords, (5) data extraction, and (6) mapping. A research question is the most significant part of all research procedures before carrying out any research. The research question is the primary tool to determine the blockchain interoperability challenges in EHRs. Related articles need to be reviewed and the interoperability challenges and their possible solutions are found. Several applications of blockchain have been presented, but these are in prototype form. Numerous challenges are persisting in the real world while implementing blockchain applications. Localization of challenges can be performed by conducting studies on relevant manuscripts. The recognition of reliable solutions for specific problems is very critical. Studying relevant articles can lead to the identification of future directions and research gaps.

Mapping techniques summarize and categorize the presented solution by researchers to solve specific EHR system interoperability problems. The research question depicts the blockchain base solution for EHRs and future direction to improve blockchains' applications for maximum performance. Several developments have been presented in the literature, which clearly defines the solution of problems. Clarity of explanations and direction makes it reliable to use blockchain in healthcare systems efficiently. Reliable findings require the implementation of various methods such as search planning, inclusion, and exclusion standard. Keyword and key term-based methods are used to search and extract EHR interoperability-related research articles to identify the challenges and solutions. Google scholar is used to search key terms such as "blockchain," "healthcare," and "interoperability of EHRs," followed by downloading articles from start to latest reports. The items mentioned above are sourced from IEEE, SCOPUS, ACM, journals, and conferences.

The research question related to the problem is composed, and research is conducted to find suitable solutions related to challenges systematically. A total of 98 articles were excluded because of the focus on "blockchain" and does not include the "blockchain in health care." The 18 standard research papers related to blockchain in EHRs with interoperability were selected for data derivation. The inclusion and exclusion criteria *n* are presented in Table 1.

The selected articles were scrutinized based on citations using the available database. Citation of relevant research article citation for once is critical. According to interoperability, the article selection was performed based on the maximum number of citations related to the systematic review of EHRs. The selection of the most relevant articles is illustrated in Figure 1 in the form of a flow chart.

Figure 1 is the flow chart representing the functioning of electronic database. The selected articles are scrutinized and then reviewed. This will provide safer ways for medical information transfer in the healthcare industry and securing it via a randomized peer-to-peer network. In general, all research articles present their keywords after the abstract of the manuscript. Related keywords to this systematic review are blockchain, interoperability, and EHRs.

3.1. Data Derivation and Mapping. Selected vital terms and keywords were used to search relevant manuscripts for systematic review, and quotes were compiled from related articles. The mapping of challenges and their possible solutions is extracted and formatted. A systematic method was adopted to highlight specific challenges related to the interoperability of EHRs and their possible solutions. The mapped solution and challenges are discussed in Results. The mapped requirements and standards are elaborated in Table 2. The selection of described standards and requirements from 18 selected articles was performed using the ATLAS.ti tool. The discussed tool is also used for keyword searching and the extraction of relevant articles and related information for the systematic literature review. The mapping techniques proved to be more efficient to screen out the most specific research question, requirements of interoperability, standards, challenges, and most appropriate interoperability of blockchain-based EHRs.

4. Bibliometric Analysis

Advancements in data collection and bibliometric analysis are playing vital role in screening out the specific and problem-oriented research articles. Several tools are being utilized in the scientific research to study and select the most relevant research. In this systematic literature review (SLR), VoSviewer tool is implemented to find and analyze the cooccurrence of citations, cooccurrence of authors, and key terms.

VoSviewer tools were utilized in this SLR to analyze the cooccurrence of citation and references. The presented network draws a network of citation of research articles based on their references. The cooccurrence of co-citation is presented in Figure 2.

Cooccurrence of terms and keyword is presented in Figure 3. The selected keywords such as healthcare, blockchain, and EHR are utilized to search the related articles. The related articles are then scrutinized based on their relevant content to the SLR. The searched 116 articles were reduced to 18 by the implementation of selection criteria of research questions and requirements. The most occurred keyword during search of relevant articles is healthcare, health information, electronic record, electronic health record, blockchain, data sharing, medical research, health insurance, health information, and EHR connections.

The bibliometric analysis also includes the authors of specific country working together or the countries working on specific problem. In this SLR, the VOSviewer is used to create the network of authors and countries working on specific domain of research. The network of such countries is presented in Figure 4.

5. Results and Discussion

The results of the systematic review are presented in this section. In the following search strategy, 116 research articles were extracted from various sources. The first selection

Table 1: Inclusion and exclusion criteria.

Criteria	Description
Inclusion	Articles published after 2021 Presenting a systematic review of healthcare systems and blockchain Introduction, conclusion, and abstract are relevant to EHRs and blockchain The article addressed the blockchain-based EHR challenges EHR implementations and utilization
Exclusion	Not cited in EHR-related articles Articles published from 2017 to 2021 Articles presentation at several sources The title does not include health care, blockchain, and interoperability

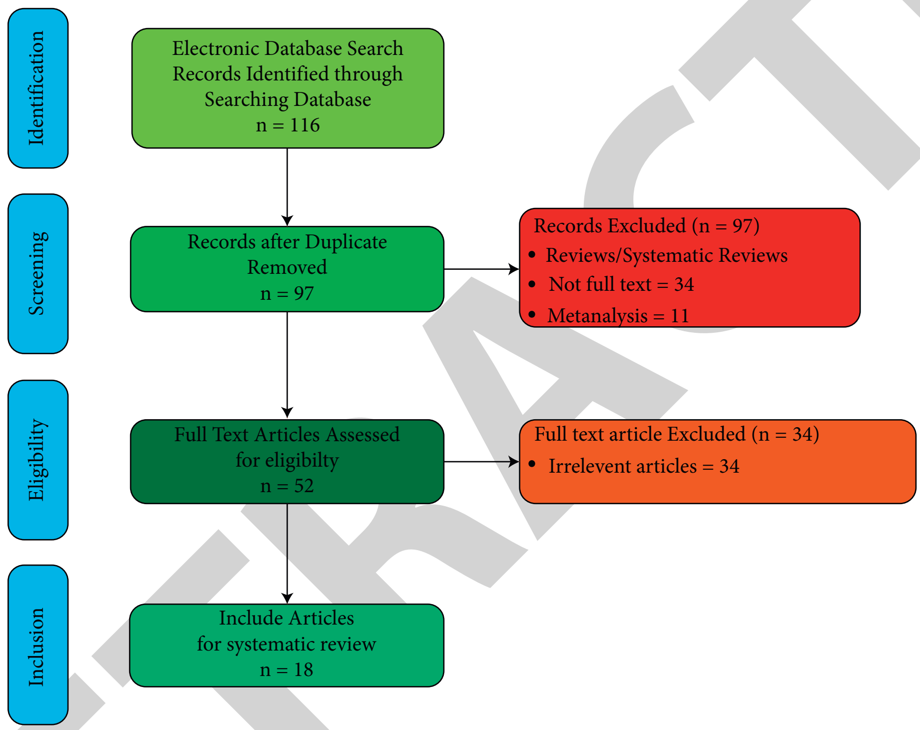

Figure 1: Article's selection criterion flow chart for systematic review.

Table 2: Requirements and standards.

Ref.	Standard	Requirements
[26]	FHIR	Information exchange
[27]	HL7	Cross-plate implementation
[28]	HITECH	Transformation
[29]	PHR	Information sharing using cross-plate APIs
[30]	Open EHR	Standard validation
[31]	DICOM	Security
[32]	SNOMED CT	Interoperability and consistency
[33]	CEN/ISO EN13606	Privacy and security
[34]	HIPAA	Privacy and consistency

method removes the duplicate records, and we have a total of 97 articles selected. The removed articles were not related to the interoperability of EHRs and blockchain. The selected articles were scrutinized further for refinement of the selection process. Exclusion criteria were implemented, and 45 articles were removed from 97 articles. During the screening process, the removed articles did not have the full text and could not qualify in the meta-analysis. The remaining 52 articles were accessed for eligibility of selection for systematic review. During the eligibility selection, 34 unrelated articles were removed from the list of selected articles. The remaining 18 articles possess the selection criteria and meet all the requirements for the systematic review of blockchain-based interoperable EHRs.

The selected articles are utilized to find the challenges and requirements of interoperable blockchain-based EHRs. The challenges, solutions, and standards of blockchain-based interoperable EHRs are divided into three research questions for the systematic review. The research questions are as follows:

Q1. What are the interoperable requirements of blockchain-based EHRs?

Q2. What are the blockchain-based interoperable standards for EHRs?

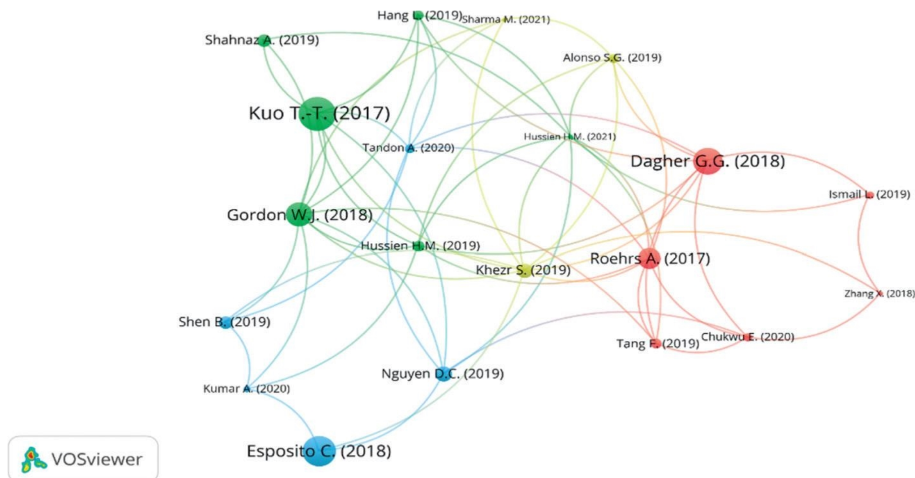

Figure 2: Reference-based cooccurrence of citations between articles.

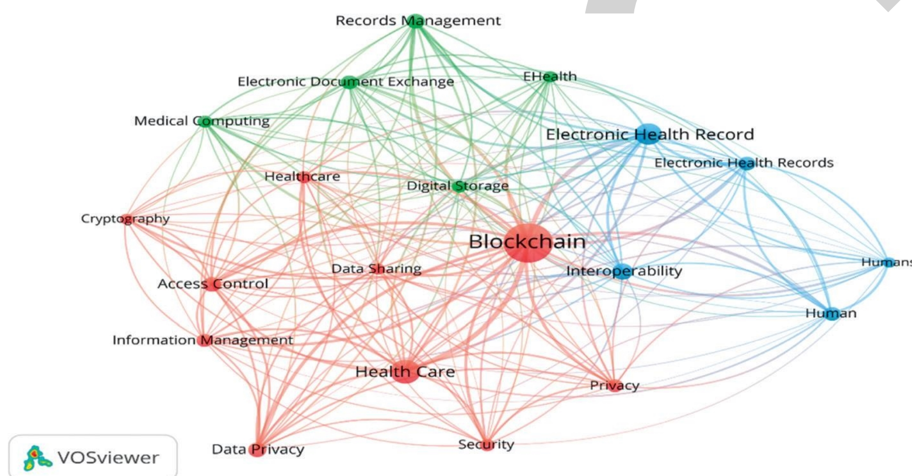

Figure 3: Cooccurrence of keywords and terms.

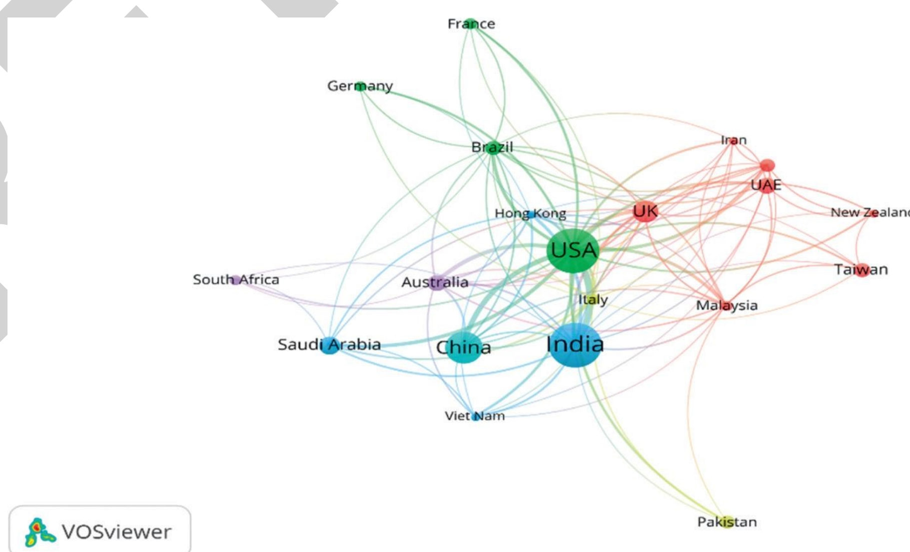

Figure 4: Network of countries working on a specific research area.

Q3. What is the best approach for BC-based EHR in solving this interoperability issue?

The research questions are discussed as follows:

Q1. What are the interoperable requirements of blockchain-based EHRs?

According to the study for this systematic literature review, interoperable requirements of blockchain-based EHRs are categorized into three levels. The levels of interoperable requirements include semantic, technological, and organizational or legal requirements. The semantic requirements illustrate the standard databases, information collection, and exchange of information in this study. The technological requirements include protocols, standards, cross-platform information sharing, and management. Legal and organizational interoperable requirements of blockchain-based EHRs consider the business model and cooperation among different governmental and private health organizations to efficiently provide healthcare services by considering the privacy and security of health information.

Blobel et al. [35] presented a semantic model of requirements for interoperable blockchain-based EHR. The presented requirement set contains a vocabulary of protocols for efficient messages and health information transmission. The method implementation at the organizational level requires a good business model coupled knowledge-sharing system. Data standard [29] adaptation is required for data integrity to provide healthcare information sharing robustly. The standard usage makes the blockchain-based EHRs helpful in health insurance claims with adequate information. Data mapping standards [36] are required to make the data sharing among various shareholders seamless. Logical models and programming language components are helpful to reduce the pressure on the federal institutions for data manipulation for health service providers. Blockchain-based systems [37] require semantic consistency. Consistency requires coding standard implementation that can improve the security of EHR. Beštek et al. [36] presented blockchain-based EHR requirement list, including robust data acquisition of data, efficient sharing mechanism among EHRs, and medical scientists to improve healthcare robust and management. EHR blockchain compliance[38] requires sharing formatted and encrypted messages between different systems and decrypting messages according to various stakeholders, which can be achieved by specifying the message standards, allowed values, and technical database according to their predefined rules. The described integrity levels of privacy and security can be achieved by increasing cooperation between vendors, industry, scientists, and health service providing institutes. Information exchange between patients and health service providers requires a set of protocols and standards to ensure data privacy and security. Data integrity and privacy using blockchain created a secure insurance and incentive system at government and private health service providing institutions. EHRs require seamless data transmission to achieve the interoperability using blockchain. The information sharing required an efficient model to transmit health information between different information processing systems. The information sharing among different systems and organizations requires legal frameworks to achieve information integrity [39, 40].

The requirements of interoperable requirements of blockchain-based EHRs are described in Table 2. The researchers presented different interoperable requirements and application methods for semantic definitions. The semantic requirements of interoperable systems are as follows:

(i) Standard method and protocols for information sharing
(ii) Unambiguous database integrity
(iii) Standard data dictionary and message protocols
(iv) Standards for data acquisitions and sharing

The technological requirements of interoperable blockchain-based EHRs extracted from the study are as follows:

(i) Comparability protocols for plug-and-play services
(ii) Allowed data elements and formats
(iii) Coding standards for robust data creations and transmission
(iv) Secure data transmission protocols

The organizational and legal requirements of interoperable blockchain-based EHRs extracted from the study are as follows:

(i) Cooperation between EHR vendors and health service providers
(ii) Business models for information sharing between EHRs and industry vendors
(iii) Professional to maintain secure data and information sharing
(iv) Insurance and incentive issue information availability

Q2. What are the blockchain-based interoperable standard for EHRs?

The interoperable stands for blockchain-based EHR application are discussed in Table 3. The researchers presented different standards for information sharing, securing, and interoperability of EHRs. The various standards adopted better implementation of blockchain-based interoperable solutions for health service providers.

The standard classification performed on better quality, workflow, privacy, security, adaptation, and secure information sharing among various stakeholders. By taking into account of the harmonization, it became essential to determine which standard had the highest

Table 3: Interoperable requirements of blockchain-based EHRs.

Ref.	Requirements: Conceptual (syntactic and semantic)	Technological	Organizational and legal
[35]	(i) Agreed vocabulary for messages and clinical documents (ii) Common terminologies and information models for advanced messages	(i) Compatibility of signals, protocols, and technical plug and play	(i) Basic business process (ii) Cooperation at the business level for knowledge sharing
[29]	(i) Use standard terms for data correctness	(i) To provide adequate healthcare, seamlessly exchange the health data	(i) Insurance, claims, and provider information in the supportive and informative infrastructure
[36]	(i) To evaluate the gaps, data element mapping to the standard terminologies	(i) Development of logical models that are independent of platform and programming language constraints	(i) Reduction in administrative burden for the reporting of federally mandated program data
[37]	(i) Consistency in semantics	(i) Resolution of technical issues of coding standards	(i) Security and privacy of healthcare data
[41]	(i) Acquisition of common dataset (ii) Obtain the consensus on the dataset from the physicians	(i) Exchange of data between different nodes of the healthcare system using robust technical standards	(i) A good healthcare informatic team to perform all activities (ii) A group of healthcare professionals to develop consensus on the specific project
[38]	(i) Ability to transmit the formatted message between two or more systems (ii) Ability to understand and utilization of transmitted message (iii) Building a controlled vocabulary	(i) Specifying the data elements such as data rules, the definition of allowed values, and data format. (ii) Agreement on the technical data models to manage the data in database management systems	(i) Cooperation between the informaticians, EHR IT vendors, industry process engineers, and clinicians
[40]	(i) Exchange the clinical database information (ii) Identification of patients and healthcare providers	(i) Adoption of previous standards for the secure transmission of data and to report the clinical data	(i) Advanced adoption for government and financial incentives, and partnership between public-private entities
[39]	(i) The transmitting systems should understand the data without any ambiguity	(i) Information transmission between several systems, and the receiving system process information to perform new actions	(i) Ensuring different legal frameworks to operate the organizations

interoperability with standards. This has been presented in Tables 4 and 5, which has helped in confirming that HL7 and FHIR have more properties of interoperability.

Q3. What are the best approaches for blockchain-based EHRs in solving this interoperability issue?

The study presented different methods and techniques to solve the interoperability issues. The researchers came up with various techniques using different standards and protocols to solve the interoperability challenges. The study presented various solutions to increase the privacy, reliability, scalability, and interoperability of blockchain-based EHRs. The comparison of approaches conducted during the study shows that [42] presented the best approach for solving the interoperability issue. The author presented an interoperable information-sharing system for EHRs. The method has compliance with all standards and protocols. The techniques follow HL7 and FHIR, and ONC standards for information among EHRs. Blockchain connected off-chain storage used for data storage and on-chain authentication method implanted to satisfy the privacy and security protocols. The authors utilized the fairness algorithm for reliability and system robustness. The proposed interoperable method is HL7, FHIR, and ONC compliance. The latest version of HL7 has semantically interoperable compliance. The best approaches are mapped using the criteria of reliability (RE), the accuracy of data (AD), data privacy (DP), security (SC), scalability (SCA), access control (AC), authentication (AUTN), authorization (AUTR), robustness (RB), anonymity (ANON), confidentiality (COFD), immutability (IMMU), standards implemented, and suggested standards. The mapping and extraction of best approaches and their characteristics are presented in Table 6.

5.1. Open Issues in Blockchain-Based EHR. This section describes some issues and challenges in EHR systems based on this systematic literature review. Following issues have been observed, including the following:

(i) In [45], the model's major drawback is the setup requirement at each healthcare facility. The healthcare facility must provide a minimum of one node to the blockchain to convert the servers into blockchain adapters. Another issue observed in the study is the scalability limitations of the blockchain protocol.

Table 4: Blockchain-based interoperable standard for EHRs.

Ref.	Blockchain-based standard available	Description
[26]	FHIR	HL7-based resource containing data attributes Standard compliance of FHIR for information exchange
[27]	HL7	FHIR-based emerging standard Robust performance on small devices
[28]	HITECH	Transformation of the healthcare system Interoperability, HER certification, and MIPS
[29]	PHR	Used HL7 for fast data sharing and tethering PHR and EHIR interchangeability using APIs
[30]	Open EHR	Designed EHR through open-source elements Validation of EHR standards through clinical implementations
[31]	DICOM	Secure transfer of medical images and health history APIs for different health system integrations
[32]	SNOMED CT	Present clinical methods in EHRs Accuracy, interoperability, and consistency
[33]	CEN/ISO EN13606	Semantic standards for EHR information sharing Privacy and security standards for interface access
[34]	HIPAA	Privacy standards for patient's data security Confident interoperable system for EHR

Table 5: Properties of blockchain-based EHR standards.

Properties	CEN13606	CEN	Open EHR	HL7	HITECH	DICOM	FHIR
Better workflow	Yes	Moderate	Yes	Yes	Yes	Moderate	Yes
Reduced ambiguity	Moderate	Yes	Yes	Yes	Moderate	Yes	Yes
Quality of care	Yes	Moderate	Moderate	Yes	Yes	Yes	Yes
Reliability	Moderate	Yes	Yes	Yes	Moderate	Moderate	Yes
Information security	Moderate	Moderate	Yes	Yes	Yes	Moderate	Yes
Security and privacy	Moderate	Yes	Moderate	Yes	Yes	Yes	Yes

Table 6: Approaches for blockchain-based EHR interoperability challenges.

Ref.		Blockchain-based EHR framework													
	Technique used	RE	AD	DP	SC	SCA	AC	AUTN	AUTR	ANON	RB	COFD	IMMU	Standard used/rule	Suggested standard
[43]	1.Ciphertext-based attribute encryption	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	—
[44]	1. Zero-knowledge proofs 2. Proxy re-encryption	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	HIPAA	FHIR
[45]	1. Distributed ledger technology 2. Smart contract 3. Hashing algorithm	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	—
[46]	1.SHA-256 algorithm 2. RSA encryption	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	HL7, FHIR

Table 6: Continued.

Ref.	Blockchain-based EHR framework														
	Technique used	RE	AD	DP	SC	SCA	AC	AUTN	AUTR	ANON	RB	COFD	IMMU	Standard used/rule	Suggested standard
[45]	1. Public key infrastructure-based asymmetric encryption 2. Digital signatures to secure shared EHR data	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	HIPAA	HL7, FHIR
[47]	1. Smart contract 2. AWS	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	HITECH, HL7	FHIR
[48]	1. Smart contract 2. Hashing method-SHA-256	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	HIPAA	—
[49]	1. Proxy re-encryption technology 2. DPoS consensus mechanism	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	No	Unified standard
[50]	1. Blockchain base lattice cryptography 2. Deep learning as a service	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	HIPAA	FHIR
[51]	1. Cryptographic hash key 2. Genetic algorithm	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Standard regulations
[52]	1. Smart contract 2. Cryptographic techniques	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	HIPAA	HL7
[53]	1. Cryptographic techniques (encryption and digital signatures)	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	—
[54]	1. Smart contract.	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	—
[55]	1. Public key cryptography 2. Proof of work algorithm 3. Smart contract	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	HIPAA	HL7, FHIR
[56]	1. Multi-authority attribute-based encryption 2. Smart contract	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	HIPAA	—
[42]	1. Smart contract 2. Digital identities	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	ONC, FHIR, Hl7	New versions of HL7 to support semantic interoperability
[57]	1. Off-chain storage and on-chain verification	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	—

(ii) Dubovitskaya et al. [45] explained in their study that if the system is not deployed correctly, then it is a high risk of system failure. A healthcare provider cannot update the permission and grant; therefore, when an unconscious patient reaches a medical center, the healthcare provider cannot access the patient's EHR information.

(iii) The privacy of patients is a significant concern in EHR systems [58]. The goal of data security is to restrict the access of unauthorized users. Data security is also a concern of healthcare providers to safeguard the patient's health information.

(iv) Bhattacharya et al. [50] raised the issue of cost. The cost is based on the lattice model. The model contains many Gaussian distribution-based parameters. This model increases the communication cost, which is a major issue.

(v) Tanwar et al. [58] have discussed the unexpected costs that may arise throughout the implementation process. Finding financial resources for EHR adoption is one of the most challenging obstacles, especially for smaller enterprises. Physicians struggle to adapt to an EHR system that does not match their present workflow. Another significant barrier to EHR adoption is patient and provider data privacy concerns. Concerns regarding data loss as a result of a natural disaster or a cyberattack are regularly expressed by stakeholders.

6. Conclusion and Future Work

The challenges presented in the literature include interoperability requirements, standards, and approaches to solve interoperability problems of blockchain-based EHRs. Table 2 presents the requirements of interoperable blockchain-based EHRs. The requirements include data acquisition, data transmission protocols, allowed data standards and formats, and coordination levels among EHRs and vendors. The interoperable standards of blockchain-based EHRs are presented in Table 3. FHIR and HL7 are the best standards for reliability, data security, privacy, and quality assessment. In Table 5, the approaches to solve the interoperability challenges are presented. 18 selected solutions against challenges presented different methods and techniques using different standards and protocols to address the interoperability of blockchain-based EHRs. The short-listed methods improve privacy, reliability, quality assessment, authentication, and interoperability.

This study may lead to future studies and research. In this study, we discuss different EHR models and answered the research questions. These answers to research questions may be utilized in the future to develop the EHR models or architectures that address the issues and challenges faced in blockchain-based electronic healthcare frameworks. Additionally, more exploration is required to resolve the current issues in blockchain-based systems combined with the Internet of things (IoT) and decentralized blockchain combined with AI, cloud computing, and big data. The organizational-level implementation should have the flexibility to adapt the cognitive solution using natural language processing and monitoring contextual facts to increase the interoperability of blockchain-based EHRs. Patient's consolidated database might be a route in electronic health records for future research. The consolidated database will house all of the patients' medical information. This will make it easier for doctors to access their patients' previous data and provide a more accurate diagnosis.

Data Availability

Data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] J.-S. Tith, H. Lee, A. B. Suzuki, N. Taira, T. Obi, and N. Ohyama, "Application of blockchain to maintaining patient records in electronic health record for enhanced privacy, scalability, and availability," *Healthcare informatics research*, vol. 26, no. 1, pp. 3–10, 2020.

[2] M. Soni and D. K. Singh, "Blockchain-based security & privacy for biomedical and healthcare information exchange systems," *Materials Today Proceedings*, 2021.

[3] D. Y. Jiang, H. Zhang, H. Kumar et al., "Automatic control model of power information system Access based on artificial intelligence technology," *Mathematical Problems in Engineering*, vol. 2022, Article ID 5677634, 6 pages, 2022.

[4] H. S. HuangChen, J. T. Jarrell, K. A. Carpenter, D. S. Cohen, and X. Huang, "Blockchain in healthcare: a patient-centered model," *Biomedical journal of scientific & technical research*, vol. 20, no. 3, Article ID 15017, 2019.

[5] M. Soni and D. K. Singh, "Blockchain implementation for privacy preserving and securing the healthcare data," in *Proceedings of the 10th Ieee International Conference on Communication Systems and Network Technologies (CSNT)*, pp. 729–734, IEEE, Bhopal, India, June 2021.

[6] G. Murugesan, T. I. Ahmed, J. Bhola et al., "Fuzzy logic-based systems for the diagnosis of chronic kidney disease," *BioMed Research International*, vol. 2022, Article ID 2653665, 15 pages, 2022.

[7] A. Dakhane, O. Waghmare, and J. Karanjekar, "AI framework using blockchain for healthcare database," *International research Journal of Modernization in engineering Technology and Science*, vol. 02, no. 8, Article ID 17017, 2021.

[8] A. Mehbodniya, I. Alam, S. Pande et al., "Financial fraud detection in healthcare using machine learning and deep learning techniques," *Security and Communication Networks*, vol. 2021, pp. 1–8, 2021.

[9] L. Wang, P. Kumar, M. E. Makhatha, and V. Jagota, "Numerical simulation of air distribution for monitoring the central air conditioning in large atrium," *International Journal of System Assurance Engineering and Management*, vol. 13, pp. 340–352, 2021.

[10] A. H. Mayer, C. A. Da Costa, and R. D. R. Righi, "Electronic health records in a blockchain: a systematic review," *Health Informatics Journal*, vol. 26, no. 2, pp. 1273–1288, 2020.

[11] T. K. Lohani, M. T. Ayana, A. K. Mohammed, M. Shabaz, G. Dhiman, and V. Jagota, "A comprehensive approach of hydrological issues related to ground water using GIS in the

Hindu holy city of Gaya, India," *World Journal of Engineering,* 6 pages, 2021.

[12] G. Murugesan, T. I. Ahmed, M. Shabaz et al., "Assessment of mental workload by visual motor activity among control group and patient suffering from depressive disorder," *Computational Intelligence and Neuroscience*, vol. 2022, Article ID 8555489, 10 pages, 2022.

[13] N. J. Vickers and J. Neil, "Animal communication: when I'm calling you, will you answer too?" *Current Biology*, vol. 27, no. 14, pp. R713–R715, 2017.

[14] J. Walker, E. Pan, D. Johnston, J. Adler-Milstein, D. W. Bates, and B. Middleton, "The value of health care information exchange and interoperability," *Health Affairs*, vol. 24, pp. W5–W10, 2005.

[15] S. N. H. Bukhari, A. Jain, E. Haq et al., "Machine learning-based ensemble model for zika virus T-cell epitope prediction," *Journal of Healthcare Engineering*, vol. 2021, Article ID 9591670, 10 pages, 2021.

[16] R. K. Garg, J. Bhola, and S. K. Soni, "Healthcare monitoring of mountaineers by low power Wireless Sensor Networks," *Informatics in Medicine Unlocked*, vol. 27, Article ID 100775, 2021.

[17] R. H. Hylock and X. Zeng, "A blockchain framework for patient-centered health records and exchange (HealthChain): evaluation and proof-of-concept study," *Journal of Medical Internet Research*, vol. 21, no. 8, Article ID e13592, 2019.

[18] G. K. Saini, H. Chouhan, S. Kori et al., "Recognition of human sentiment from image using machine learning," *Annals of the Romanian Society for Cell Biology*, vol. 25, no. 5, pp. 1802–1808, 2021.

[19] S. Mehta, K. Ackery, and A. Ackery, "Future of blockchain in healthcare: potential to improve the accessibility, security and interoperability of electronic health records," *BMJ Health & Care Informatics*, vol. 27, no. 3, Article ID e100217, 2020.

[20] C. C. Agbo, Q. H. Eklund, and J. M. Eklund, "Blockchain technology in healthcare: a systematic review," *Healthcare*, vol. 7, no. 2, pp. 56–68, 2019.

[21] A. Shahnaz, U. Qamar, and A. Khalid, "Using blockchain for electronic health records," *IEEE Access*, vol. 7, Article ID 147782, 2019.

[22] D. C. Nguyen, P. N. Pathirana, M. Ding, and A. Seneviratne, "Blockchain for secure EHRs sharing of mobile cloud based e-health systems," *IEEE Access*, vol. 7, Article ID 66792, 2019.

[23] O. Kubassova, F. Shaikh, C. Mahler, and M. Mahler, "History, current status, and future directions of artificial intelligence," *Precision Medicine and Artificial Intelligence*, vol. 2, no. 5, pp. 1–38, 2021.

[24] R. Jabbar, N. Fetais, M. Krichen, and K. Barkaoui, "Blockchain technology for healthcare: enhancing shared electronic health record interoperability and integrity," in *Proceedings of the 2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT)*, vol. 6, no. 4, pp. 310–317, Doha, Qatar, Febraury 2020.

[25] F. Alam KhanAlam Khan, M. Asif, A. Ahmad, M. Aljuaid, and H. Aljuaid, "Blockchain technology, improvement suggestions, security challenges on smart grid and its application in healthcare for sustainable development," *Sustainable Cities and Society*, vol. 55, no. 55, Article ID 102018, 2020.

[26] S. Pais, D. Parry, and Y. Huang, "Suitability of fast healthcare interoperability resources (FHIR) for wellness data," in *Proceedings of the 50th Hawaii International Conference on System Sciences*, Hawaii, HI, USA, January 2017.

[27] G. C. Lamprinakos, A. S. Mousas, A. P. Kapsalis et al., "Using FHIR to develop a healthcare mobile application," in *Proceedings of the 4th International Conference on Wireless mobile Communication and Healthcare-Transforming Healthcare through Innovations in mobile and Wireless Technologies*, pp. 132–135, Athens, Greece, November 2014.

[28] J. D. HalamkaHalamka and M. Tripathi, "The HITECH era in retrospect," *New England Journal of Medicine*, vol. 377, no. 10, pp. 907–909, 2017.

[29] R. Saripalle, C. Russell, and M. Russell, "Using HL7 FHIR to achieve interoperability in patient health record," *Journal of Biomedical Informatics*, vol. 94, no. 3, Article ID 103188, 2019.

[30] D. Kalra, T. Heard, and S. Heard, "The openEHR foundation," *Studies in Health Technology and Informatics*, vol. 115, pp. 153–173, 2005.

[31] M. Mantri, S. Taran, and S. Gaur, "DICOM integration libraries for medical image interoperability: a technical review," *IEEE Reviews in Biomedical Engineering*, vol. 3, pp. 10–18, 2020.

[32] D. Lee, N. De Keizer, F. Cornet, and R. Cornet, "Literature review of SNOMED CT use," *Journal of the American Medical Informatics Association*, vol. 21, no. e1, pp. e11–e19, 2014.

[33] P. Muñoz, J. D. Trigo, I. Martínez, A. Escayola, J. García, and J. Garcia, "The ISO/EN 13606 standard for the interoperable exchange of electronic health records," *Journal of Healthcare Engineering*, vol. 2, no. 1, pp. 1–24, 2011.

[34] L.-C. Huang, H.-C. Chu, C. Y. Lien, C.-H. Kao, and T. Kao, "Privacy preservation and information security protection for patients' portable electronic health records," *Computers in Biology and Medicine*, vol. 39, no. 9, pp. 743–750, 2009.

[35] B. Blobel and Bernd, "Interoperable EHR systems - challenges, standards and solutions," *European Journal for Biomedical Informatics*, vol. 14, no. 2, pp. 10–19, 2018.

[36] S. A. Matney, B. Heale, S. Hasley et al., "Lessons learned in creating interoperable fast healthcare interoperability resources profiles for large-scale public health programs," *Applied Clinical Informatics*, vol. 10, no. 01, pp. 087–095, 2019.

[37] J. G. Shull and J. Germaine, "Digital health and the state of interoperable electronic health records," *JMIR medical informatics*, vol. 7, no. 4, Article ID e12712, 2019.

[38] D. J. Slotwiner, R. L. Abraham, S. M. Al-Khatib et al., "HRS white paper on interoperability of data from cardiac implantable electronic devices (CIEDs)," *Heart Rhythm*, vol. 16, no. 9, pp. e107–e127, 2019.

[39] G. Bincoletto and Giorgia, "Data protection issues in cross-border interoperability of Electronic Health Record systems within the European Union," *Data & Policy*, vol. 2, no. 3, pp. e3–50, 2020.

[40] P. R. Sutton and T. H. Payne, "Interoperability of electronic health information and care of dialysis patients in the United States," *Clinical Journal of the American Society of Nephrology*, vol. 14, no. 10, pp. 1536–1538, 2019.

[41] D. StanimirovićStanimirović and M. Beštek, "Special Topic Interoperability and EHR: combining openEHR, SNOMED, IHE, and Continua as approaches to interoperability on national eHealth," *Applied Clinical Informatics*, vol. 08, no. 03, pp. 810–825, 2017.

[42] P. Zhang, J. White, D. C. Schmidt, G. Lenz, and S. T. Rosenbloom, "FHIRChain: applying blockchain to securely and scalably share clinical data," *Computational and Structural Biotechnology Journal*, vol. 16, no. 5, pp. 267–278, 2018.

[43] L. Wang, Z. Song, C. Huang, S. Wang, and J. H. Wang, "Guest editorial: special section on data-enabled intelligence in complex agricultural systems," *Intelligent Automation & Soft Computing*, vol. 26, no. 5, pp. 947-948, 2020.

[44] B. Sharma, H. Raju, and J. Singh, “Blockchain-based interoperable healthcare using zero-knowledge proofs and proxy Re-encryption,” in *Proceedings of the 2020 International Conference on COMmunication Systems & NETworkS (COMSNETS)*, pp. 1–6, Bangalore, India, January 2020.
[45] Y. Zhuang, L. R. Sheets, Y.-W. Chen, Z.-Y. Shae, J. J. P. Shyu, and C. R. Shyu, “A patient-centric health information exchange framework using blockchain technology,” *IEEE journal of biomedical and health informatics*, vol. 24, no. 8, pp. 2169–2176, 2020.
[46] H.-A. Lee, H.-H. Kung, J. G. Udayasankaran et al., “An architecture and management platform for blockchain-based personal health record exchange: development and usability study,” *Journal of Medical Internet Research*, vol. 22, no. 6, Article ID e16748, 2020.
[47] L. Cagliero, L. Canale, and L. Farinetti, “VISA: a supervised approach to indexing video lectures with semantic annotations,” in *Proceedings of the 2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC)*, pp. 226–235, Milwaukee, WI, USA, July 2019.
[48] E.-Y. Daraghmi, Y.-A. Yuan, and S.-M. Yuan, “MedChain: a design of blockchain-based system for medical records access and permissions management,” *IEEE Access*, vol. 7, no. 3, Article ID 164595, 2019.
[49] X. Liu, Z. Wang, C. Jin, and G. Li, “A blockchain-based medical data sharing and protection scheme,” *IEEE Access*, vol. 7, no. 3, Article ID 118943, 2019.
[50] P. Bhattacharya, S. Tanwar, U. Bodkhe, S. Kumar, and N. Kumar, “Bindaas: blockchain-based deep-learning as-a-service in healthcare 4.0 applications,” *IEEE Transactions on Network Science and Engineering*, vol. 8, no. 2, pp. 1242–1255, 2021.
[51] A. F. Hussein, N. ArunKumar, G. Ramirez-Gonzalez, E. Tavares, J. M. R. de Albuquerque, and V. H. C. De Albuquerque, “A medical records managing and securing blockchain based system supported by a genetic algorithm and discrete wavelet transform,” *Cognitive Systems Research*, vol. 52, no. 2, pp. 1–11, 2018.
[52] G. G. Dagher and J. Mohler, M. Milojkovic, P. B. Marella, Ancile: privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology,” *Sustainable Cities and Society*, vol. 39, pp. 283–297, 2018.
[53] Q. Xia, E. Sifah, A. Smahi, S. Zhang, and X. Zhang, “BBDS: blockchain-based data sharing for electronic medical records in cloud environments,” *Information*, vol. 8, no. 2, pp. 44–52, 2017.
[54] Q. I. Xia, K. O. Sifah, J. Asamoah et al., “MeDShare: trust-less medical data sharing among cloud service providers via blockchain,” *IEEE Access*, vol. 5, no. 7, Article ID 14757, 2017.
[55] A. Azaria, Ariel Ekblaw, T. Vieira, and A. Lippman, “Medrec: using blockchain for medical data access and permission management,” in *Proceedings of the 2016 2nd International Conference on Open and Big Data (OBD)*, pp. 25–30, Vienna, Austria, August 2016.
[56] H. Jin, C. Xu, Y. Luo, and P. Li, “Toward secure, privacy-preserving, and interoperable medical data sharing via blockchain,” in *Proceedings of the 2019 IEEE 25th International Conference on Parallel and Distributed Systems (ICPADS)*, pp. 852–861, Tianjin, China, December 2019.
[57] S. Jiang, J. Cao, H. Wu, Y. Yang, M. Ma, and J. He, “Blochie: a blockchain-based platform for healthcare information exchange,” in *Proceedings of the 2018 Ieee International Conference on Smart Computing (Smartcomp)*, pp. 49–56, Sicily, Italy, June 2018.
[58] S. Tanwar, K. Evans, and R. Evans, “Blockchain-based electronic healthcare record system for healthcare 4.0 applications,” *Journal of Information Security and Applications*, vol. 50, no. 8, Article ID 102407, 2020.