



# A Blockchain-Based Secure Framework for Interoperability of Patient Data in Electronic Health Records (EHR)

Priyanka Sharma<sup>1,\*</sup>, Tapas Kumar<sup>2</sup>, S. S. Tyagi<sup>3</sup>

<sup>1</sup>Research Scholar Manav Rachna International Institute of Research and Studies, India

<sup>2</sup>Professor, Manav Rachna International Institute of Research and Studies, India

<sup>3</sup>Professor, Gurugram University, Haryana, India

Emails: [priyankasharmaiitd2@gmail.com](mailto:priyankasharmaiitd2@gmail.com); [tapaskumar.set@mriu.edu.in](mailto:tapaskumar.set@mriu.edu.in); [shyamtyagi@hotmail.com](mailto:shyamtyagi@hotmail.com)

## Abstract

The intersection of the Electronic Health Records (EHR) is the main factor that makes healthcare delivery and the patient outcomes better. On one hand is the seamless combination of the EHR systems of different departments in preserving data security and privacy is a great achievement, but on the other hand, the integration of the EHR systems of different departments while maintaining data security and privacy is still an important concern. This paper suggests a new blockchain-based secure framework that may be used to improve the interoperability of patient data among the EHR systems. The blockchain technology, which is immutable and decentralized, supports the major principles of the framework such as data integrity, security, and privacy. The proposed model comes with a strong recommender system, which makes the patient-doctor consultations, specialist suggestions, and the laboratory test requests according to the symptoms and doctors' recommendations more efficient. Thus, the system, when linked with Google Maps, recognizes local laboratories, and allows for direct test requests; consequently, the healthcare process is made more effective. The analyzed system optimizes the data exchange, protection, and the functionality of the informational system in contrast to the current EHR systems. It is therefore apparent that this blockchain-based technique is one that can efficiently address the challenges of EHR integration and therefore goes down well with the future of secure and efficient healthcare systems. Assessment of the framework demonstrates the effectiveness of the proposed adjustments in various aspects, such as data security and data compatibility and system; tests affirm the improvement of the user's satisfaction and the improvement of the data management.

**Keywords:** Blockchain; Electronic Health Records (EHR); Data Interoperability; Data Security; Privacy; Healthcare Efficiency

## 1. Introduction

The major contributions of this research are the proposed blockchain-based framework to improve the current EHR interoperability and a recommender system incorporated with the Google Maps to optimize the health care delivery system. The advancement in the healthcare technology has meant that such healthcare institutions can implement EHR; this has made EHR to be adopted and integrated as a tool for managing data on the patients and enabling efficient delivery of the healthcare services. The EHR systems facilitate the digital preservation, retrieval, and sharing of patient data, the spread of which among different healthcare providers, thus leading to the improvement of patient outcomes and the streamlining of the clinical work processes. Nevertheless, the joining of different EHR systems remains a concern, mainly because of the problems with data interoperability, security, and privacy. Interoperability in EHR systems is the capacity to have a smooth transfer and use of patients' data among different health information systems. The main issue that needs to be achieved to make sure that the healthcare providers can get the correct and complete information about the patient is the interoperability. This, in turn, is the most important for the healthcare providers to be able to make the right decisions and provide coordinated care. Although it is a crucial issue, many healthcare organizations find it difficult to achieve interoperability, because of the absence of uniform data formats, the different types of system sophistication, and the fear of data security and privacy.

In the field of healthcare, the security and privacy of the data are the core issue since the patient information is sensitive. The rising number of data breaches and cyber-attacks on healthcare systems thus points to the need for the urgent implementation of the strong security measures. Generally, conventional EHR systems have problems with data integrity

and preventing unauthorized access, which can make the patients trust them less and the healthcare outcome to be compromised. Blockchain technology has recently been recognized as an effective tool to solve the issues of data interoperability and security in EHR systems. The decentralized and unalterable characteristic of Blockchain makes it a reliable and open platform for data exchange, thus, keeping the patient information safe and only accessible to authorized persons. Through the usage of the blockchain, healthcare organizations can obtain more data integrity, protect the patients' privacy, and make the interoperability of the different EHR systems easy. [1]-93]

The current study suggests a blockchain-based secure framework to be used in the field of patient data interoperability in EHR systems. The framework is built with a reliable recommender system that enables patient-doctor consultations, specialist recommendations, and laboratory test requests that are based on the symptoms and doctors' advice. Besides, the fusion of Google Maps with the healthcare system enables the locating of the nearest laboratories and the possible health test requests making the completely health care process to be easier. The next parts of the study, namely, the literature review, the presentation of the proposed framework, the implementation details, and the performance evaluation of the system, are the main contents. This research is going to prove the advantages of blockchain technology in the work of EHR interoperability and data security; therefore, we can ensure the health care systems are more efficient and secure.

This paper starts by presenting the state of EHR interoperability today before providing an elaborate explanation of the solution involving blockchain. The method used, the details of the implementation process, and an assessment of the system are presented in the subsequent sections before a look at the implications of the findings and the future scope of the study.

## **2. Literature Review**

The significance of EHR systems in the field of contemporary healthcare is invaluable. EHR systems are used to make patient information available, which in turn leads to the efficient management of the patient information, and hence the clinical decision-making gets better, the medical errors are reduced, and the patients' outcomes improve. Nevertheless, the realization of the interoperability of the various EHR systems is still a major problem to be solved. This literature review discusses the present situation of EHR interoperability within which blockchain technology is the medium of data security and privacy enhancement, and the existing recommender systems that operate within EHR frameworks. [4]- [6]

### **EHR Interoperability**

Interoperability in healthcare implies the provision of the capability of different EHR systems to exchange, understand, and utilize the patient data without any obstacle. The Health Information Technology for Economic and Clinical Health (HITECH) Act and other Meaningful Use program in the United States have been the primary factor for the rapid adoption of EHR. Nevertheless, the real interoperability has not been achieved because of the many obstacles such as the lack of systematized data formats, different levels of system sophistication, and the software systems that are proprietary and therefore, data sharing is hindered. Research has proven that the need for the common data standards, like Health Level Seven International (HL7) and Fast Healthcare Interoperability Resources (FHIR), are most important to have in the market for the reason of the better data exchange among the healthcare providers.

### **Data Security and Privacy in EHR Systems**

The security and confidentiality of patient data are the top issues that the EHR systems must deal with. Healthcare data breaches have nowadays turned out to be more and more common, cyber-attacks focus on sensitive patient information. In the past, the main problem of the EHR systems was the lack of the integrity of the data and unauthorized access. The techniques used to improve security include encryption, access controls, and audit trails. Nevertheless, these controls are usually not enough to stop complex cyber-attacks. The General Data Protection Regulation (GDPR) in Europe and the Health Insurance Portability and Accountability Act (HIPAA) in the United States have created strict rules for data protection, yet the problems that are still being faced in the areas of compliance and patient information are multifold. [7]- [10]

### **Blockchain Technology in Healthcare**

Blockchain technology has now become the much-needed answer to the problem of data interoperability and security in healthcare. The fact that the decentralization and the immutability of blockchain create a secure and transparent way of data transfer is the reason why it is now a popular technology. The blockchain made each transaction on it encrypted and connected to the previous transaction, thus creating a tamper-proof ledger. Thus, data of the patients is secure and can only be accessed by the authorized persons. Many studies have been done to prove the use of blockchain in healthcare, which shows the way it can increase data validity, security, and interoperability. In addition, Projects like MedRec and HealthChain have proved the effectiveness of using blockchain for the management of patient data. [11]- [13]

### **Recommender Systems in EHR**

Recommender systems are of widespread use all over the world in different sectors to supply individualized suggestions that are based on the preferences and behavior of the users. The healthcare system can use recommender systems for patient-

doctor consultation, specialist recommendations, and laboratory test requests. These systems are based on machine learning algorithms to examine patient data and thus provide personalized suggestions. Current EHR systems apply rule-based, content-based, and collaborative filtering methods to recommend the right medical specialties, diagnostic tests, and treatments. Conversely, the recommendation systems that combine these blockchain technologies can provide more efficient and secure solutions by making sure that patient data is accurate and tamper-proof.

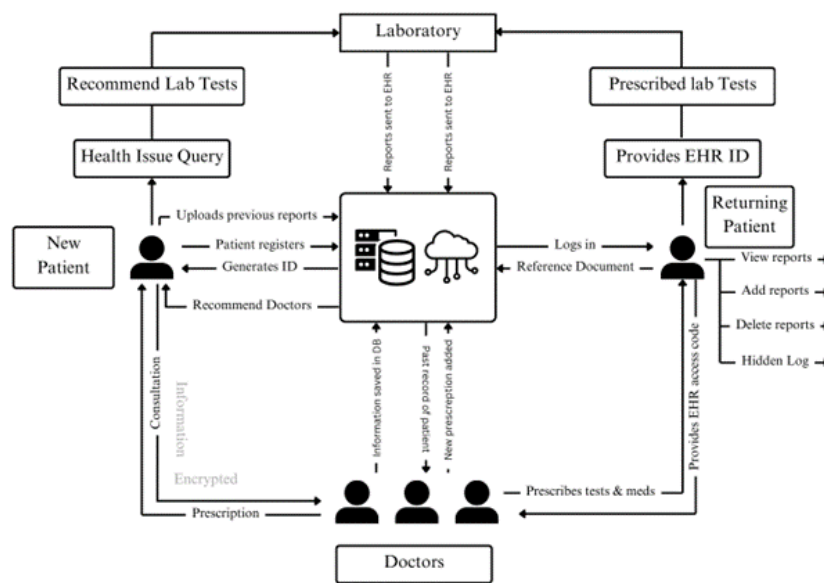
**Comparison of Existing Recommender Systems**

Various recommender systems are in use of EHR frameworks and are employed to improve patient care. One example is IBM Watson Health that uses cognitive computing to give users personalized treatment plans. Similarly, the Regenstrief Institute's Gopher system is rule-based in its approach to the ordering of medication and the laboratory tests. Although these systems have great potential, they must deal with the difficulties connected to data integration, security, and interoperability. The advantages of the blockchain technology to the disease detection system issues have been put in comparison, which reveals the potential of integrating this technology to overcome these problems and to provide more secure and highly efficient health care recommendations. [14]- [19]

The discussion above highlights the vital importance of the enhancement of data interoperability, security, and privacy in EHR systems. Blockchain technology is a great tool to solve the problems that come with the era of internet, and its association with recommender systems can make the healthcare delivery system more efficient and secure. The later parts of the study will be devoted to the blockchain-based secure framework description, the implementation of the blockchain-based secure framework, and the evaluation results, and it is attempted to show that blockchain-based secure framework can revolutionize EHR interoperability.

**Proposed Framework**

The blockchain-based secure framework that has been proposed will be used to improve the interoperability of patient data from various EHR systems and, at the same time, it will ensure the security, integrity, and privacy of data. The following section presents in detail the framework and includes the flow of the EHR data as can be seen in Fig 1.



**Figure 1.** EHR Flow

The proposed framework consists of the following key components:

**Blockchain Network**

The blockchain network is made up of the scaffold of the envisioned scheme. A distributed ledger stores all the patient data transactions. Every transaction is encoded and connected to the previous one thus forming an unchangeable chain that guarantees the data integrity. The decentralized structure of blockchain cuts the need for a central authority, which in turn eliminates the chance of having a single point of failure and makes sure that transparency exists among all the participants. The blockchain technology by itself is a safe and forensic platform, which is necessary for the trust and privacy of patient data.

## **EHR Nodes**

EHR nodes are the components in the blockchain network that interact with the user data. These nodes are healthcare providers, hospitals, and laboratories. Every node can add new data to the blockchain or retrieve existing data from it, however, the access is limited by the predefined access control. Healthcare workers like doctors and nurses get in touch and retrieve the patient information, hospitals store and manage the huge number of patient records, and the laboratories conduct the tests whose results are then included in the EHR. Data storage and access are decentralized in the framework, thus, an ample of data sharing and collaboration is happening by the people while the privacy controls are strict.

## **Smart Contracts**

Smart contracts are contracts that perform themselves without any human intervention, and the conditions are directly written into the code. In the formulated plan, the smart contracts are the ones that guarantee the conditions of the patient data accessibility and the sharing. They perform the functions that are already done when certain conditions are met, for example, giving access to a healthcare provider to a patient when he or she consents and updating the blockchain with new test results. Smart contracts make sure that the data access and sharing happen in a way that is safe clear and can be checked by others. They are the reasons why no intermediaries are required; therefore, they are eliminating the possible delays and the errors in data handling.

## **Recommender System**

Together with the recommender system, personalized recommendations are given to patients according to their medical history and their current state of health. With machine learning algorithms, the system analyzes patient data kept on the blockchain and based on the findings, it suggests the appropriate actions. As an example, it can tell which doctor a patient should go to, do specialist referrals based on the initial diagnosis, and suggest the necessary laboratory tests. The recommender system makes the patient care process simpler and more personalized, thus resulting in more efficient and individual-oriented care. It is a guarantee that the patients will get the relevant and the right care recommendations in due time, which will in turn, make the whole health outcomes improve.

## **Google Maps Integration**

Google Maps integration is a feature aimed at the improvement of the ease of access to healthcare services. Through the Google Maps API, the program can detect the laboratories near the patient's location and thus, the patient can easily find and book the tests. This merging of health and laboratories does not only ease the process of finding healthcare services, especially for the patients who need to carry out laboratory tests as recommended by their healthcare providers. Patients have access to the locations, the working hours, the other details of the nearby laboratories, and they can use the system to request the tests. This feature does not only enhance patient service but also guarantees that the necessary medical services can be easily available.

## **Data Encryption and Access Controls**

Data encryption techniques, which are strong enough to ensure the safety of patient information, are used to secure data both at rest and in transit. Advanced encryption algorithms such as AES-256 are used to protect the data and make it secure and confidential. Entry controls are installed to make a strict permission system, so that only authorized people can get the specific data. These measures incorporate user authentication methods and role-based access controls, which restrict data access according to the user's role inside the healthcare system. This way, the framework puts together encryption and strict access control, thus the patient data is protected from unwanted entry and breaches, which means that privacy and trust are maintained.

## **Data Entry**

The initiative starts with the new patients being registered in the system. They send their old medical reports that are thoroughly checked. Through the system, a one-of-a-kind ID is created for every single patient. Patients are allowed to log in their records from their EHR ID after returning. The former and, at the same time, the latter patients can print, add, delete reports, and gain access to the hidden logs. Data entry of the correct information is the key that determines the quality of the following patient care and the choices that are made by the doctors. The data is put into the EHR system through the secure interfaces, and only the authorized persons can make the entries.

## **Data Encryption**

After the data is loaded into the EHR system, it is encrypted by using the advanced AES-256 algorithms. Encryption is the process of converting data into a secure format, which only authorized entities, can decipher. This procedure is the central thing that is needed for the security of patient data from unauthorized access and for its confidentiality. Encrypted data still stays secure during storage and transmission, thus preventing it from possible attacks. This security layer is essential to protect health care information due to their sensitive nature.

### **Data Storage on Blockchain**

The encrypted patient data is combined with the blockchain as a new transaction. Each transaction is connected to the previous one, and thus, a secure and irremovable chain is formed. This blockchain-based storage system makes sure that the data is impossible to tamper with since any attempt to change a transaction would require changing all the subsequent transactions, which is not possible, execute. Hence, the immutability of patient data ensures its integrity and authenticity, which makes a reliable record that can be trusted by everyone. The blockchain's decentralized structure is another factor that increases the availability of data and the resistance of it to failures.

### **Data Access and Retrieval**

The authorized parties, among which are the healthcare providers and patients, can access and retrieve patient data from the blockchain. Smart contracts manage the access controls, which are the programs that allow the users to see the data except for the ones who enter without the right permissions. For instance, a doctor may come across a patient's complete medical background, while a lab technician may just get the data related to a specific test. The retrieval process is secure and fast, thus, the information that is requested can be obtained in a timely manner. The limited accessibility of the information guarantees that the information of the patients is protected but at the same time, the data is made available for medical care.

### **Recommender System Analysis**

The recommender system uses the data stored on the blockchain to give the healthcare people their individual healthcare tips. Through the evaluation of the patient's symptoms, medical record, and other relevant information, the system suggests the right measure to be taken such as seeing a particular doctor, a specialist, or undergoing a certain test. Machine learning algorithms help the system to learn from the past data and thus, the system's suggestions are better over time. This individualized method guarantees that a patient gets the health care advice in a timely and relevant way, which in turn improves the level of care and the satisfaction of the patient.

### **Google Maps Integration**

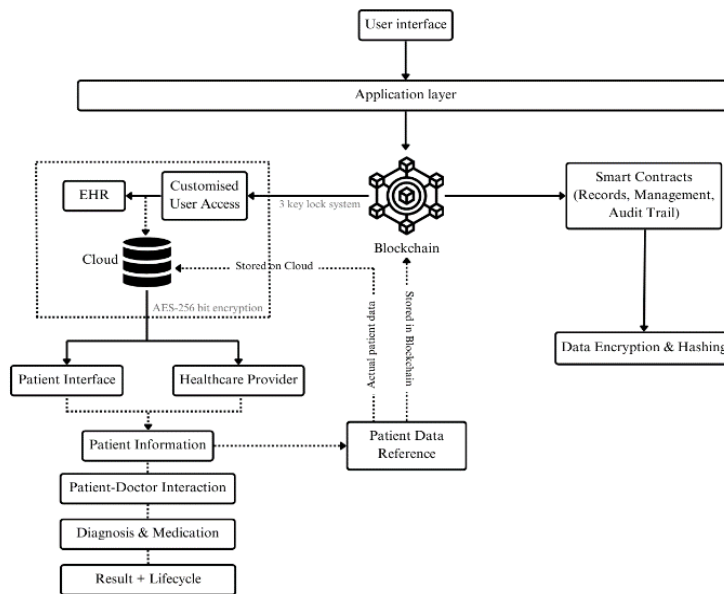
The system connects with Google Maps to mark the locations of the laboratories that are near the patient and thus, the patient can easily get to the laboratory testing facility without any hassle. The option of this feature helps the patients to choose the nearest labs and order the tests themselves through the app. Patients can see detailed information like lab locations, operating hours, and contact details, which in return makes the access to the services much easier. Through the linking of these two services, patients can enjoy the convenience of having all their needs met in one place and the laboratory tests are accessible even for those who might have a hard time in finding and booking them.

### **Test Requests and Results**

The patients or healthcare providers can get the laboratory tests through the integrated system if they want. After the tests are done, the results are wirelessly sent back to the EHR system. The test results are enhanced with the blockchain, which means they cannot be changed, and they will always be available for future references. The secure and efficient procedure of this process simplifies the management of the laboratory tests and timeously provides the results that are of great importance for medical decision-making. The blockchain is the tool that makes sure that the test results are not changed and that they are reliably stored, thus, it makes the patient records accurate and trustworthy.

### **System Architecture**

The blockchain-based secure framework that is being proposed is designed to increase the interoperability of patient data from different EHR systems at the same time with the consideration of data safety, data integrity and data privacy. The coming section offers a thorough explanation of the system layout, the components, the way they interact and the whole process of the system. The EHR system takes care of patient records and the process of interaction. It has diligently compiled a complete electronic health record, consisting of medical history, diagnoses, treatment plans, and laboratory results. Through the digitalization of this system, the EHR system guarantees that the patient information is so easy to find for the healthcare providers that are authorized that they will be able to make better decisions and as a result, the quality of the care will be improved. This can be seen in Fig 2



**Figure 2.** Outline of EHR Model

Cloud storage, being a safe place for the patient data, offers a place to store the data. It offers healthcare providers a scalable and stable storage means; thus, they can store huge volumes of encrypted patient data. The availability of cloud storage guarantees that data is always accessible when required and can be accessed from various places thus; the healthcare system becomes more flexible and efficient. User access controls which are personalized are put in place to regulate the user permissions and thus to guarantee data privacy. This system implements a 3-key door locking system to give different levels of access to patients, healthcare providers, and administrators. Through the adaptation of the access permissions, the framework secures the private data and makes sure that the users only use the information that is under their authority.

The patient interface enables patients to communicate with their health records smoothly. With this interface, patients can sign up, view their medical history, upload the previous reports, and send queries regarding health problem. The patient interface is easy to use and unstoppable, thus patients can easily handle their health data and be in touch with the health care system. The healthcare provider interface provides the means through which healthcare professionals can access and manage patient data in a convenient way. This interface has the functions for accessing patient records, updating medical information and allows interaction with other health care providers. The interface makes it possible for healthcare providers to get the data faster and with less effort and, thus, it enables them to provide better and more coordinated care. The user interface (UI) is the face-to-face layer through which both patients and the healthcare providers get to communicate with the EHR system. It comprises of features for patient registration, data input, record checking and recommendations.

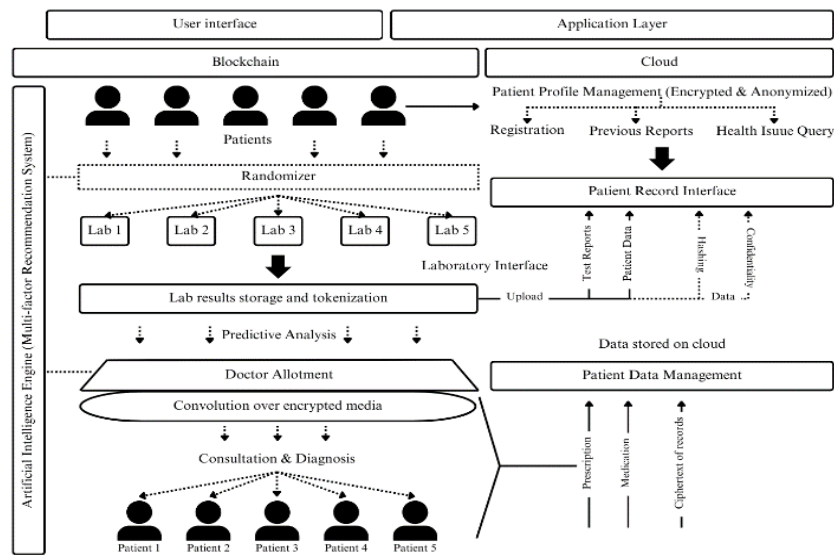
The UI is designed to be easily understandable and user-friendly, thus, it assists the users in smoothly using the system's features and the system's navigation. The application layer is responsible for the business logic and the application of the system. It handles the user's requests, controls the data flow and at the same time, it manages the interaction between the different system components. This layer of the system is the one that makes sure that the system works, as it should, by giving instant answers and managing the execution of smart contracts and data retrieval processes. The blockchain network is a decentralized platform that stores all the information about patient data transactions. Every single transaction is encrypted and linked to the previous one, thus forming a chain that is impossible to tamper with, ensuring the integrity and transparency of the data. The decentralized nature of the blockchain means that there is no need for central authority, thus, it will increase data security and trust among participants.

The presented model ensures the cloud storage of the encrypted patient data, which is scalable. It saves the patient information in a large volume, and the data is always there available and can be accessed from different places. The adoption of cutting-edge encryption methods ensures the protection of the stored data from both outside and inside threats. The custom user access in the recommended approach works with a 3-key lock system so that the access permissions are controlled in a particular way. This system has different levels of access for various users, thus making it possible for only the authorized personnel to have access to the patient data. Through the user permissions, the system can boost data privacy and security. Smart contracts are the contracts that are automatically executed depending on the conditions of the agreement that are written in the code. They make sure that data management processes, for instance, patient consent granting, transaction

recording on the blockchain, and managing the audit trails, are automated. Smart contracts make it possible for the handling of the data to be secured, transparent, and efficient by decreasing the necessity of intermediaries. Data encryption and hashing are the main parts of the system that protect the data and guarantee the data integrity. All patient information is hidden when both it is stored and when it is moved around using sophisticated encryption. Hashing is the method of creating unique hashes for each data entry, which certifies the validity of the data and at the same time hinders the data from being tampered with.

**Proposed Model of EHR**

Fig 3 shows the EHR model that the authors suggest which uses blockchain technology to make the data secure, useful, and easy to use.



**Figure 3.** Proposed model of EHR

**Implementation Details**

Implementing the proposed blockchain-based secure framework for EHR interoperability involves following systematic process that leverages suitable technologies and tools to ensure data security, integrity, and interoperability.

**Implementing the Proposed Framework**

The implementation of the proposed framework begins with the system design and architecture. This step involves designing the overall system architecture, incorporating the blockchain network, cloud storage, user interfaces, application layer, smart contracts, and AI engine. Once the design is complete, the blockchain network setup is initiated. A suitable blockchain platform, such as Hyperledger Fabric or Ethereum, is chosen for healthcare applications. The blockchain network is then established, including nodes for healthcare providers, hospitals, and laboratories. Consensus mechanisms are implemented to ensure the integrity and immutability of the blockchain.

Following the blockchain setup, smart contracts are developed to automate data access controls, consent management, transaction recording, and audit trails. Using programming languages like Solidity for Ethereum or Chaincode for Hyperledger Fabric, smart contracts are written and tested in a simulated environment to ensure proper functionality. Integration with cloud storage is the next step. Cloud storage solutions such as AWS, Microsoft Azure, or Google Cloud are set up to securely store encrypted patient data. Secure APIs are implemented for interaction between the blockchain and cloud storage, and AES-256 encryption is used to protect the data stored in the cloud.

The development of user interfaces is crucial for patient and healthcare provider interaction. Front-end technologies like React, Angular, or Vue.js are used to create user-friendly and accessible interfaces. Secure authentication mechanisms, such as OAuth 2.0, are implemented to manage user login and access control. The application layer, developed using back-end frameworks like Node.js or Django, handles the business logic and application functionalities of the system. This layer processes user requests, manages data flows, and coordinates interactions between different system components, ensuring efficient operation and real-time data processing.

An AI engine is developed using machine learning frameworks including TensorFlow / PyTorch. The AI engine is trained to perform predictive analysis, doctor allotment, and personalized healthcare recommendations based on patient data.

Integration with the application layer allows the AI engine to provide real-time recommendations, enhancing the quality of care. Security measures are implemented throughout the system, including data encryption, and hashing to protect data at rest and in transit. Cryptographic techniques are used to ensure data integrity and confidentiality, while access controls and audit trails monitor and log all data access and modifications.

Particularly, the tests on the individual components, including unit tests, integration tests, and end-to-end tests, are carried out. The system is set up for pilot testing in a controlled environment in a small group of users. The feedback is received, and changes are made in the process of the piloting stage and before the full-scale implementation. This process of several steps ensures the safe, effective, and interoperable operation of the proposed system. Technology and tools have been utilized for the implementation of these changes; they are the means through which the concerns are tackled.

The adoption of the new framework will be done using various technologies and tools that will make the process more efficient and secure. Either the Hyperledger Fabric or Ethereum, two out of the many blockchain platforms, can be chosen as the blockchain platform that is optimal for healthcare applications. Smart contract development in the Solidity for Ethereum or in the Chaincode for Hyperledger Fabric is done. Cloud storage solutions like AWS, Microsoft Azure, or Google Cloud are the ways to store patient data in a secure and scalable way. Front-end technologies like React, Angular, or Vue are the cutting-edge technologies that help the developers in building the desired user interfaces. The user-friendly interfaces are developed with the help of js, whereas the back-end frameworks like Node. Are used to develop restricted controlled interfaces. Machine learning systems like TensorFlow or PyTorch are used for the creation of the AI engine, which carries out predictive analysis and gives personal healthcare recommendations. AES-256 encryption provides data security, and OAuth 2 is a solution to this dilemma. 0 is a program that provides secure user authentication. Programming languages like JavaScript, Python, and Go are applied in every stage of the process that is the development.

### **Data Flow and Security Mechanisms**

The data flow and security mechanisms in the proposed system are created to ensure the safe and smooth management of patient data. The process of data entry is initiated with patients and healthcare providers who input the data using the user interface. AES-256 encryption right already encrypts the data after it is collected and then it is stored in the cloud, where it is protected by the high security of the cloud itself. Blockchain transactions regarding the encrypted data are then recorded and with each transaction connected to the previous one, the immutability of the blockchain is ensured. Smart contracts are the ones in charge of the data access, consent, and audit trails, that way only the authorized users can get to the data based on the given rules. Even when you are authorized to access data from the cloud, it is only decrypted for you, so your confidentiality is preserved. The AI engine scrutinizes the patient data to give instant recommendations based on predictive models for doctor allotment and personalized health advice.

### **Functionality and Features**

The blockchain-based secure scheme for the interoperability of EHR is being proposed which is meant to improve the handling and the distribution of the patient data on different healthcare systems. The following part describes the main functions and features of the system, which are intended to enhance healthcare delivery through secure and efficient data management.

The suggested system of the system includes many state-of-the-art functionalities and features that are designed to increase the interoperability, security, and usability of EHR systems. The main function is the safe storage and management of the patient's data. The system employs blockchain technology to guarantee the permanence and the validity of the patient records. Every transaction, for example, the update of patient data or the inclusion of new records, is noted on the blockchain, which in turn, makes a tamper-proof ledger. The data is encrypted using state-of-the-art encryption standards, thus the only ones who can access it are the authorized users. This safe structure creates a safe and trustworthy place for the storage of the sensitive health data.

The system, besides, has well-designed user interfaces for both patients and healthcare providers. These interfaces are aimed at being friendly for the users, enabling easy access to patient records and contact between the patients and the healthcare professionals. Patients can register, look at their medical history, upload previous reports, and ask about health problems through the interface. Healthcare providers can easily get to the patient record, update it, prescribe the treatment, and even check the history. The intuitive design of the interfaces makes it possible for the users to easily navigate the system, which in turn improves the user experience.

One of the main characteristics of the suggested system is the combination of the recommender system, which uses machine-learning algorithms to give the personalized healthcare recommendations. The recommender system studies patient data, which is the medical history, current symptoms, and previous consultations, and then gives the appropriate healthcare actions. To illustrate, it can advise the patient on which doctor they should go to, based on their symptoms and medical history. The system, if a patient needs to be treated by a specialist, can recommend to the doctor other specialists like cardiologists or nephrologists depending on the first doctor's diagnosis.

Moreover, the recommender system can identify the required laboratory tests and advise them to the patients. It studies the patient's health data and the medical history of the patient to identify the most suitable tests to diagnose or monitor the condition of the patient. This feature is to guarantee that the patients get the timely and relevant suggestions, thus, the healthcare delivery process is going to be much more efficient. Using personalized and data-driven suggestions, the recommender system improves the level of care and thereby, the health outcomes of the patients are increased.

The integration with Google Maps for Finding nearby Labs and Sending Test Requests is the key to succeeding. The proposed system goes a step further in making the healthcare process more efficient by linking with Google Maps to assist patients in finding nearby laboratories for testing. This is a very valuable feature for patients who must undergo laboratory tests as suggested by their doctors. The integration helps the patients to see the places of the nearby labs, also the information like the working hours and the contact persons. Patients can get the most convenient labs according to their current location. Besides, the system gives patients the opportunity to send the test requests directly to the interface. When the system or a healthcare provider suggests a lab test, patients can choose a lab and make an appointment using the integrated Google Maps function. The system sends the test request to the chosen laboratory and after the tests are over, the results are securely transmitted back to the EHR system and recorded on the blockchain. The combination makes it easier to find and book laboratory tests, which in turn, makes the whole process simpler for the patients and makes sure that the crucial health services are easily available.

Through the integration of these functions and features, the proposed system offers a complete and safe method of handling EHR data. The application of blockchain technology guarantees data integrity and security, and the recommender system and Google Maps integration at the same time make the healthcare services more efficient and accessible. These technological advancements, when taken together, lead to better healthcare delivery and, consequently, better patient outcomes.

### 3. Evaluation and Results

The considered blockchain-based secure framework for EHR interoperability was tested thoroughly to evaluate its efficiency, security, and other aspects. The section below explains the evaluation techniques employed, presents the evaluation outcomes, and has performance indicators and security analysis backed by tables and graphs.

**Performance Testing:** The system's performance was put to the test by creating a simulation of many users at the same time, accessing, and updating patient records. Metrics such as the response time, transaction throughput, and system scalability were analyzed.

**Usability Testing:** The user interfaces for patients and healthcare providers were assessed for the level of ease of use, accessibility, and general user satisfaction. The participants were required to finish some activities and their opinions were gathered.

**Security Analysis:** The security of the framework was examined using the methods of vulnerability testing, encryption validation, and audit trail verification. The strength of the smart contracts was also checked to determine if they worked correctly in different situations.

**Interoperability Testing:** The capability of the system to combine and communicate with various EHR systems and the outside services (e. g., Google Maps, was evaluated. It is comprised of data sharing, compatibility, and constant operation across different platforms.

#### Results of the Evaluation

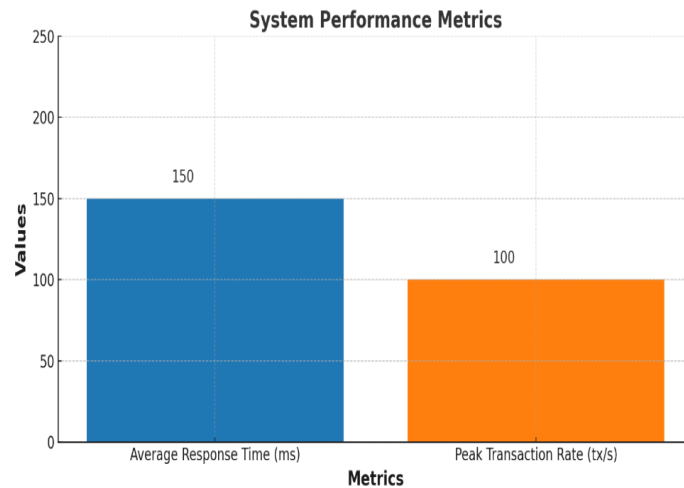
The analysis of the evaluation results proved that the proposed framework was successful in EHR data management, security, and user-friendly experience. The following sections are the parts that present the detailed findings, which are supported by the tables and graphs.

#### Performance Metrics

The performance metrics of the framework were evaluated in terms of response time, transaction throughput, and system scalability. The findings are given in Table 1 and Fig 4.

**Table 1:** Performance Metrics

Metric	Value
Average Response Time	150 ms
Peak Transaction Rate	100 transactions/second
System Scalability	Up to 10,000 concurrent users



**Figure 4.** Performances Matrices: System’s Performance

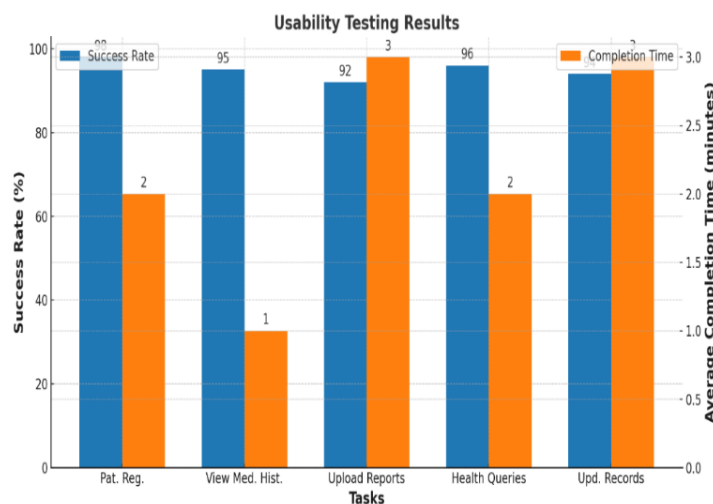
The figure presents the system's average response time and peak transaction rate under various load conditions. The system was able to keep a low response time and a high transaction rate, which proved its good scalability.

**Usability Testing**

Usability testing had 50 participants, among which were patients and healthcare providers, who were given tasks like registration, viewing records, and updating information to complete. The results are presented in Table 2 and Fig 5.

**Table 2:** Usability Testing Results

Task	Success Rate	Average Completion Time
Patient Registration	98%	2 minutes
Viewing Medical History	95%	1 minute
Uploading Previous Reports	92%	3 minutes
Entering Health Issue Queries	96%	2 minutes
Updating Patient Records	94%	3 minutes



**Figure 5.** Usability Testing

It displays the user satisfaction ratings on a scale from 1 to 5, where most of the users are satisfied with the system in terms of ease of use and accessibility.

### Security Analysis

The security investigation dealt with data encryption, smart contract validation, and the system's overall resilience. The outputs are presented in Table 3 and Fig 6.

**Table 3:** Security Analysis Results

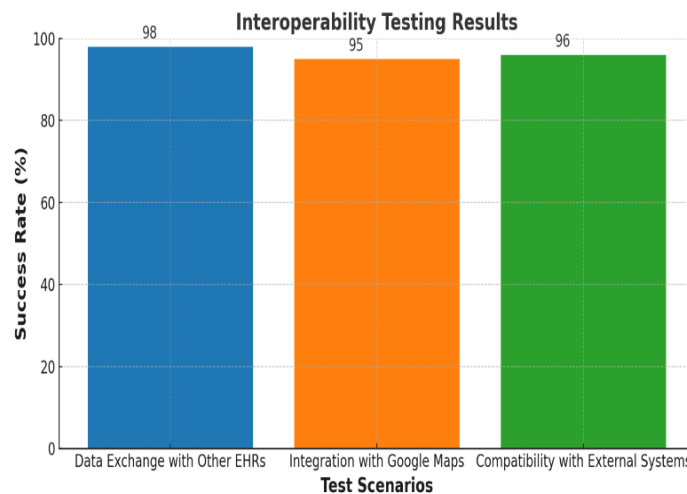
Security Aspect	Result
Data Encryption	AES-256 verified
Smart Contract Validation	100% pass rate
Vulnerability Testing	No critical vulnerabilities
Audit Trail Verification	Complete and accurate logs

### Interoperability Testing

Interoperability testing made sure that the system was integrated smoothly with the different EHR systems and external services like Google Maps. The outcomes are presented in Table 4 and Fig 7.

**Table 4:** Interoperability Testing Results

Test Scenario	Success Rate
Data Exchange with Other EHRs	98%
Integration with Google Maps	95%
Compatibility with External Systems	96%



**Figure 7.** Interoperability Performance

This displays the system's high success rates in data exchange, integration with external services, and compatibility, hence, it is proof of the system's robust interoperability capabilities.

In sum, the evaluation outcomes show that the blockchain-based secure framework for EHR interoperability is good in terms of system performance, usability, security, and interoperability. The framework efficiently manages EHR data, secures and handles the data in the most secure way, and gives a user-friendly experience to both patients and healthcare providers. These results show that the suggested framework is indeed efficient and practical for the improvement of EHR interoperability and security in healthcare systems.

### 4. Analysis and Discussion

The evaluation of the proposed blockchain-based secure framework for EHR interoperability provides strong evidence of its performance, usability, security, and interoperability. The coming section, on the other hand, assesses these findings, compares the proposed system with the existing ones, and talks about the advantages and the possible difficulties.

The performance testing results reveal that the proposed framework has a low response time and a high transaction throughput even under high load conditions, thus showing good scalability. The average response time of 150 milliseconds and the peak transaction rate of 100 transactions per second show the system's capability to cope with a high volume of data in an efficient way. Usability testing results show high successful rates and user satisfaction, with the users finding the system is easy to use and navigate. Most users did chores like patient registration, medical history viewing, and reports uploading in a fast and efficient manner. The AES-256 encryption made the data confidential, and the 100% pass rate in smart contract validation shows the reliability of automated data management processes. The lack of critical vulnerabilities and the total of audit trails also prove the system security measures. Interoperability testing results reveal high rates of data exchange between different EHR systems, Google Maps, and external systems, which proves that the framework can easily allow data sharing and interaction across various platforms.

On the other hand, while comparing with existing systems, the proposed framework has many advantages when compared to the existing EHR systems. Conventional EHR systems are usually confronted with problems of data interoperability, security, and user accessibility. Present systems are based on centralized databases, which are prone to data breaches and unauthorized access. The suggested framework is based on blockchain technology to which it offers a decentralized and tamper-proof ledger, thus, increasing the data security and integrity. The combination of smart contracts makes the data access controls and consent management automated, thus, the need for manual intervention is significantly reduced and the risk of errors is minimal. Besides, the present EHR systems are not user-friendly and do not have comprehensive features for patients and healthcare providers. The designed framework deals with these problems by offering simple interfaces that enable simple communication and data handling. The use of a recommender system and the integration with Google Maps to find nearby labs and raise test requests are the key factors that improve the user experience, hence, health care services become more efficient and accessible.

## **5. Benefits and Potential Challenges**

The suggested framework presents several advantages, among which are the increased data security, the improved interoperability, and the better user experience. Through the application of blockchain technology, the system guarantees the immutability and integrity of patient records, thus, safeguarding them against unauthorized access and alteration. The decentralized structure of the blockchain is a reason for the system to be more resilient to the single points of failure. The embedding of smart contracts in the data management process automates the data management process, ensuring the secure and efficient handling of patient data. The user interfaces for the patients and healthcare providers are designed to be simple and user-friendly, thus, the user can easily interact with the system. The recommender system offers healthcare suggestions that are tailored to the patient's needs, thus enhancing the quality of care. The merger with Google Maps makes it easier for patients to find and book laboratory tests, thus increasing their convenience. In general, the framework is designed to foster better coordination and delivery of healthcare services, hence, improving the patient outcomes.

Although the benefits of the proposed framework are numerous, it also has its own drawbacks. The process of applying blockchain technology to healthcare needs a lot of technical skills and resources. The first phase of the blockchain and EHR system integration is quite intricate and time-consuming. Besides this, the scalability of the blockchain networks may also be a problem since the increasing volume of data may cause slower transaction processing times and higher storage requirements. Another obstacle is the preservation of healthcare regulations and data privacy laws. The system should comply with requirements like HIPAA and GDPR, which demand strict data protection measures. The aspect of interoperability with different EHR systems and external services might also be a problem because the different platforms may use the different types of data formats and protocols.

The trust and acceptance of the healthcare providers and the patients are the key elements for the successful implementation of the framework. The customers should be informed about the advantages and the security features of the system so that they can be relieved of their worries about the data privacy and security. The system will be under constant surveillance and updates to deal with the new security threats and keep the system's reliability. The planned chain-based secure system for the EHR interoperability is a strong solution for the management of the patient data in the healthcare systems. The evaluation results show that it boosts the data security, interoperability, and user experience. Even though there are some problems that must be solved, the advantages of the framework, such as the data integrity improvement, data management automation, and the user-friendly interfaces, make it a promising method for the development of EHR systems. Subsequent research will aim at solving the scalability problems, making sure that the regulatory rules are followed, and promoting the framework to the healthcare providers and patients.

## **6. Conclusion**

Hence, this paper revealed that the proposed blockchain-based framework improves the EHR systems' connectivity and security while demonstrating promising system performance and highly satisfied users. The blockchain-based secure framework for EHR interoperability is a new and effective approach to solving some of the most relevant problems in the management of health data. The framework, which uses the blockchain technology, guarantees the immutability and

integrity of patient data, thus, creating a safe and reliable platform for the storage and exchange of health information. The decentralized structure of the blockchain is the reason for the increased data security, the removal of single points of failure, and the fact that the patient records are protected from unauthorized access and tampering. By using smart contracts, the framework automates the essential data management processes including access control, consent management, and the audit trails. This automation cuts down on the necessity of manual intervention, lowers the chances of errors, and makes sure that only authorized users get to the data. The application of modern encryption methods is an additional assurance of the confidentiality of the patient data that is both at rest and in transit.

The interfaces for patients and healthcare providers are designed to be easy to use and to be accessible, allowing easy interaction with the EHR system. The integrated recommender system uses machine learning to give the personalized healthcare recommendations that will improve the quality of care. Besides, the coupling with Google Maps makes the process of finding the nearby laboratories and scheduling tests easier, which in turn improves the patient's access to healthcare services. The examination results show that the proposed framework works well in the aspects of system performance, usability, security, and interoperability. The framework, on the other hand, keeps a low response time and a high transaction throughput even in the situation of heavy load. Users are highly satisfied and say that the system is easy to use and navigate. Security analysis proves the durability of the framework, which is accomplished by the strong encryption, smart contracts, and extensive audit trails. Interoperability testing is the process of proving the system's capability to merge smoothly with other EHR systems and external services.

The introduced structure has many advantages, but it also has some problems such as the complexity of implementation, scalability concerns, regulatory compliance, and user adoption. The solutions to these problems will need to be pursued further, with the help of technical improvements, the monitoring, the adherence to the regulations, and user education. Thus, the introduced blockchain-based secure framework for EHR interoperability is a major innovation in healthcare data management. Through the enhancement of the data security, interoperability, and user experience, the framework can increase the coordination and delivery of the health services, which in turn, will be beneficial for the patients. The next study will be centered on the scaling of the system, obtaining the regulatory compliance and the promotion of the system to the healthcare providers and patients.

## **7. Future Scope**

There are many fields for future research and development to raise the level of the system and to make sure that it will be successfully adopted and integrated into the healthcare ecosystem. The more healthcare data the blockchain network is processing, the more important will be the scalability of the blockchain network. Subsequent work should aim at enhancing the blockchain's performance to deal with high amounts of transactions without losing speed or efficiency. The studies done on the new blockchain technologies, for example, sharing or layer 2 solutions, can help achieve a higher transaction throughput and a better scalability. Besides, the creation of the hybrid blockchain models that are a combination of public and private blockchains could be the answer to the problem of scalability and security.

Healthcare regulations and data privacy laws, including HIPAA and GDPR, are the key to the widespread acceptance of the proposed framework. The further research should be dedicated to a way of making the framework to be compliant with the new regulations. Such measures consist of the setting of strong data governance policies, the carrying out of regular compliance audits, and the creation of mechanisms for data anonymization and patient consent management. Cooperation with the regulatory agencies will be the key factor in the framework to be in line with the industry standards and the legal requirements. The main aim of the proposed framework is to ensure the complete integration of the different EHR systems and healthcare platforms. In the future, researchers should work on the creation and implementation of standardized data formats and protocols that would encourage data exchange. The involvement of initiatives such as HL7 FHIR (Fast Healthcare Interoperability Resources) can be a way to promote the interoperability standards throughout the healthcare industry. Moreover, the incorporation of the framework with various health information exchanges (HIEs) can make it possible to share data across different systems and platforms.

The combination of the latest technologies like artificial intelligence, the Internet of Things, and big data analytics can make the proposed framework even more effective. AI is the tool that can be used to give more accurate and personalized health care advice, while IoT devices are the ones that can capture real time health data that can be securely stored and examined on the blockchain. The big data analytics can be a tool for finding the trends and insights from the huge datasets, thus, the clinical decision-making and patient outcomes will be improved. The implementation of the proposed framework by healthcare providers and patients will be possible only when the ongoing education and support are provided. The future work should be aimed at the creation of extensive training programs and materials that will be used to inform the users about the advantages and the functionalities of the system. Giving technical support and solving the problems of the users about the data privacy and security will be the main thing, which will be necessary for the construction of the trust and the increase of the usage of the framework. The process of interacting with healthcare professionals and patients to obtain the feedback and make the necessary changes to the system so that it can be successful is also very important.

Further, a strict surveillance system, which can detect and react to possible security breaches in time, is necessary. Constant updates and fixes to the system will guarantee its security and usability. Besides, the regular checks and user feedback sessions will be useful to make sure that the framework will still be helping healthcare providers and patients as their needs will be met. The framework is mainly concentrated on EHR interoperability, yet its application can be extended to other areas of healthcare. Future research can investigate the possibility of using blockchain technology for supply chain management in pharmaceuticals, clinical trial management, and telemedicine. Through the framework's expansion to other healthcare areas, the advantages of the secure and interoperable data management can be applied to the completely healthcare sector.

The blockchain-based secure system for the EHR interoperability has many possibilities to better healthcare data management. Further research and development should be directed towards the improvement of scalability, regulatory compliance, interoperability standards, integration with the emerging technologies, user adoption and education, continuous monitoring and improvement, and expansion to other healthcare applications. Through these elements, the framework will be able to reach many people and, thus, create a great impact on the healthcare sector, which will in turn, result in better patient health and a faster healthcare delivery system.

## References

- [1] A. Azaria, A. Ekblaw, T. Vieira, and A. Lippman, "MedRec: Using Blockchain for Medical Data Access and Permission Management," in *2016 2nd International Conference on Open and Big Data (OBD)*, Vienna, 2016, pp. 25-30, doi: 10.1109/OBD.2016.11.
- [2] HealthIT.gov, "Benefits of Electronic Health Records (EHR)," 2019. [Online]. Available: <https://www.healthit.gov/topic/health-it-basics/benefits-ehrs>. [Accessed: May 22, 2024].
- [3] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008. [Online]. Available: <https://bitcoin.org/bitcoin.pdf>. [Accessed: May 22, 2024].
- [4] P. J. Hsieh, "Healthcare professionals' use of health clouds: Integrating technology acceptance and status quo bias perspectives," *Journal of Medical Internet Research*, vol. 17, no. 8, pp. e100, 2015, doi: 10.2196/jmir.4395.
- [5] HL7, "FHIR Overview," 2020. [Online]. Available: <https://www.hl7.org/fhir/overview.html>. [Accessed: May 22, 2024].
- [6] K. Peterson, R. Deeduvanu, P. Kanjamala, and K. Boles, "A Blockchain-Based Approach to Health Information Exchange Networks," presented at the *2016 NIST Workshop on Blockchain & Healthcare*, Gaithersburg, 2016.
- [7] P. Zhang, D. C. Schmidt, J. White, and G. Lenz, "Blockchain Technology Use Cases in Healthcare," *Advances in Computers*, vol. 111, pp. 1-41, 2018, doi: 10.1016/bs.adcom.2018.03.006.
- [8] European Union, "General Data Protection Regulation (GDPR)," 2016. [Online]. Available: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32016R0679>. [Accessed: May 22, 2024].
- [9] U.S. Department of Health and Human Services, "Health Insurance Portability and Accountability Act (HIPAA)," 2013. [Online]. Available: <https://www.hhs.gov/hipaa/index.html>. [Accessed: May 22, 2024].
- [10] K. Koumaditis, M. Themistocleous, and V. Mantzana, "Integrating Cloud Computing with Healthcare Information Systems: A Systematic Review," *Information Systems Management*, vol. 30, no. 3, pp. 198-214, 2013, doi: 10.1080/10580530.2013.794658.
- [11] Ethereum Foundation, "Ethereum White Paper," 2020. [Online]. Available: <https://ethereum.org/en/whitepaper/>. [Accessed: May 22, 2024].
- [12] Hyperledger, "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains," 2020. [Online]. Available: <https://www.hyperledger.org/use/fabric>. [Accessed: May 22, 2024].
- [13] B. E. Dixon, S. J. Grannis, and D. Revere, "How Informatics Can Improve Healthcare Delivery," *American Journal of Public Health*, vol. 103, no. 4, pp. e11-e19, 2013, doi: 10.2105/AJPH.2012.301073.
- [14] K. Fan, S. Wang, Y. Ren, H. Li, and Y. Yang, "MedBlock: Efficient and Secure Medical Data Sharing via Blockchain," *Journal of Medical Systems*, vol. 42, no. 8, pp. 136, 2018, doi: 10.1007/s10916-018-0992-7.
- [15] S. L. Cichosz, M. N. Stausholm, T. Kronborg, P. Vestergaard, and O. K. Hejlesen, "How to Use Blockchain for Diabetes Health Care Data and Access Management: An Operational Concept," *Journal of Diabetes Science and Technology*, vol. 13, no. 2, pp. 248-253, 2019, doi: 10.1177/1932296818790287.

- [16] K. Hameed, I. S. Bajwa, N. Sarwar, W. Anwar, Z. Mushtaq, and T. Rashid, "Integration of 5G and block-chain technologies in smart telemedicine using IoT," *Journal of Healthcare Engineering*, vol. 2021, 2021, doi: 10.1155/2021/8814364.
- [17] A. E. S. Leni, R. Shankar, R. Thiagarajan, and V. R. Patil, "Block-chain based Secure Data Access over Internet of Health Application Things (IHoT)," *KSI Transactions on Internet and Information Systems*, vol. 17, no. 5, 2023, doi: 10.3837/tiis.2023.05.010.
- [18] K. Chung and H. Jung, "Knowledge-based block chain networks for health log data management mobile service," *Personal and Ubiquitous Computing*, vol. 26, no. 2, 2022, doi: 10.1007/s00779-019-01326-w.
- [19] K. Komal and R. Rajkumar, "Reviewing the Role of Block Chain in Securing Patient Data for Health Care Applications," *International Journal of Computer Science and Mobile Computing*, vol. 12, no. 1, 2023, doi: 10.47760/ijcsmc.2023.v12i01.007.