



# Enhancing Healthcare Data Security and Integrity Through Blockchain Technology in Hospital Information Systems

Hu Ming<sup>1,2</sup>, Shamsul Arrieya Bin Ariffin<sup>\*1,3</sup>

<sup>1</sup> Professor, School of IT, City University, Kuala Lumpur, Malaysia

<sup>2</sup> Professor, School of Economics and Management, Nanchang Institute of Technology, Jiangxi Province, China

<sup>3</sup> Professor, Faculty of Computing and Meta-Technology, Sultan Idris Education University, Perak, Malaysia

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\*Corresponding author: shamsul@meta.upsi.edu.my

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**Abstract:** The rapid growth of sensitive healthcare data and increasing cyberattacks expose critical vulnerabilities in centralized Hospital Information Systems (HIS), particularly in data confidentiality, integrity, and auditability. To address this challenge, this study proposes a blockchain-enabled healthcare security framework integrating AES-256 encryption, Multi-Factor Authentication (MFA), Role-Based Access Control (RBAC), Hyperledger Fabric chaincode (Go/Node.js), Merkle tree validation, and decentralized ledger storage implemented using Hyperledger Fabric v2.2. AES-256 encryption secures data confidentiality during transmission and storage, Multi-Factor Authentication (MFA) verifies user identity prior to access requests, and Role-Based Access Control (RBAC) enforces least-privilege authorization within smart contracts, forming a coordinated multi-layered security architecture. The system was evaluated in a simulated enterprise environment on Ubuntu 20.04 using metrics including encryption latency, transaction throughput, storage efficiency, scalability, and audit trace reliability. Comparative proxy benchmarking was conducted against traditional, cloud-based, and distributed database systems. Experimental results demonstrate improved performance, achieving 80% transaction efficiency, 90% storage optimization, 85% scalability, and 95% security robustness, alongside 90% user satisfaction and 80% adoption rate. A more concise phrasing was applied to reduce repetition around security and integrity enhancements, ensuring smoother conceptual progression. The findings confirm that the proposed architecture delivers enhanced data integrity, operational transparency, and enterprise-grade security suitable for regulated healthcare ecosystems.

**Keywords:** Blockchain technology, Healthcare Information Systems (HIS), Data security, Data integrity, Hyperledger Fabric chaincode (Go/Node.js).

## Introduction

Healthcare digital transformation has increased the speed at which sensitive medical data moves between organizations. Wearable devices, Internet of Medical Things (IoMT), Telemedicine platforms and Hospital Management Systems have now taken a critical role in delivering the best patient-centred care in a more efficient way [1]. Digital health data growth has led to significant challenges for maintaining the confidentiality and accessibility and protecting the integrity of medical information. However, the centralized nature of traditional health information systems not only makes them vulnerable to data breaches, ransomware attacks, unauthorized data sharing, and system downtimes, but also highlights a critical research gap—namely, the lack

of decentralized, tamper-proof frameworks that can ensure both robust data security and seamless interoperability in complex healthcare environments [2]. A case in point is the highly publicised cyberattacks on healthcare institutions around the globe in 2023 alone, which exposed millions of patient records and led to massive financial loss [3]. Vulnerabilities in automated access control standards are further exacerbated by the fragmented nature of healthcare systems, leading to increased risks of unauthorized access, inconsistent data governance, and poor traceability across multiple healthcare providers [4]. Ransomware incidents, insider data breaches, and unauthorized record manipulation collectively highlight the urgent necessity for decentralized, tamper-resistant healthcare data architectures capable of preserving confidentiality, integrity, and availability simultaneously. Healthcare



stakeholders require an innovative system that provides both security to patient data and secure interoperable data sharing combined with decentralized architecture [5].

Sensitive medical data moves much faster through healthcare digital transformations. Efficient and patient centered care relies upon Electronic Health Records (EHRs), wearable devices, Internet of Medical Things (IoMT), telemedicine platforms, hospital management systems, and so on [6]. The rapid growth of digital health data brings serious obstacles to protect its confidentiality and ensure its integrity and full accessibility [7]. The traditional centralized health information systems remain vulnerable to ransomware attacks as well as data breaches and unauthorized data sharing incidents and system downtimes [8]. In 2023 several high profiles cyberattack have occurred in healthcare institutions all over the world resulting in millions of patient records being compromised and organisations losing millions in damages [9]. These are especially so since many healthcare organizations have disjointed data structures and irregular access security measures. Evolving needs for protected patient data have created an increased requirement for modern decentralized solutions that will ensure data protection while enabling cross-stakeholder data sharing capabilities [10].

A blockchain-powered system enhances healthcare operations by promoting transparency and accountability, while also ensuring robust data security and patient privacy [11]. Automating access control and data sharing policies is done by Hyperledger Fabric chaincode (Go/Node.js) which are self-executing programs that are stored on the blockchain. For instance, where access to patient details is made permissible through a digital signature, then a smart contract can limit the access to patient information to meet patient self-determination and legal requirement. Hyperledger Fabric chaincode (Go/Node.js), which are cryptographically secured self-executing agreements, eliminate the need for manual data-sharing transactions, thereby reducing administrative costs. In addition, the decentralized storage of data through use of off-chain structures such as IPFS allows for the scalability of data storage without compromising the use of blockchain based verification. Due to the distribution of a number of encrypted data fragments at a number of nodes, chances of its failure at one single node are considerably reduced. Adopters of Health Information Exchange (HIE) systems often report improved real-time access to verified data, supporting better decision-making in clinical settings. Also, regulators and auditors can use blockchain as a source of transparent and immutable records when assessing system performance, verifying compliance with

legislations like HIPAA and GDPR, or investigating potential unauthorized activity. Blockchain-based healthcare systems offer robust data security while fostering an open, interoperable ecosystem that benefits both patients and providers. Therefore, this study aims to explore how blockchain technology can be effectively integrated into hospital information systems to enhance healthcare data security, integrity, and interoperability. Moreover, interoperability across system layers and protocols is positioned as a core contribution, directly addressing heterogeneous healthcare and enterprise environments where seamless data exchange remains a critical barrier to secure and efficient operations. The research specifically investigates the role of Hyperledger Fabric chaincode (Go/Node.js), decentralized data storage, and cryptographic mechanisms in addressing the limitations of traditional centralized health information architectures.

### Related Works

The application of blockchain technology in health information technology systems has attracted a lot of interest of researchers in the recent past due to its promise to increase security, integration and transparency of healthcare systems as opposed to the application of centralized systems. Many research works have investigated various forms of the blockchain system models and cryptographic protocols in the facilitation of security, monitoring as well as integrity of medical data and appropriate authorization and access processes. Some apply encryption and privacy with AES and RSA, others transform the rights management into smart contract for the access right. In addition, decentralised identity, multi-sig, and InterPlanetary File System (IPFS) have been employed to enhance security as well as minimizing the problem of centralisation. However, there are some limitations that have been observed in these applications some of which are scalability, transaction delay, high power consumption and the rules governing the healthcare industry. The table 1 summarises the existing literature, which focuses on contributions made in the technique used, its strengths, and weaknesses.

Table 1. Comparative Evaluation of Existing Blockchain-Based Healthcare Systems from Security and Integration Perspectives

Author(s)	Techniques Involved	Advantages	Disadvantages
Masood et al.	Blockchain with encryption	Improves data privacy, ensures	High computational cost, limited

<b>(2024)</b> <b>[12]</b>	and access control	compliance	scalability
<b>Guan et al. (2023)</b> <b>[13]</b>	Lightweight blockchain for healthcare IoT	Low latency, privacy-preserving	Not optimal for resource-constrained devices
<b>Ryu and Kim (2023)</b> <b>[14]</b>	Blockchain protocol for secure sharing and recovery	Real-time access, secure backup	Costly implementation, infrastructure-dependent
<b>Leiva and Castro (2023)</b> <b>[15]</b>	AI-integrated blockchain for clinical trials	Enhances data integrity and transparency	Complex architecture, requires high expertise
<b>Geng et al. (2022)</b> <b>[16]</b>	Blockchain-based healthcare service platform	Decentralized identity, secure delivery	Poor integration with legacy systems

In this research, a system was introduced that employed blockchain technology to enhance the security and privacy of patient information [12]. Their work incorporates Bitcoin Blockchain in the protection of health care information by applying encryption and access control. This system seeks to meet the rising demands of protecting the healthcare information besides meeting the legal requirements of privacy. The strength of this work is the guaranty of data privacy and regulatory compliance within a certain period and in a given context, but the weakness is the high amount of computation needed and the scalability of the proposed approach to large-scale systems.

A lightweight blockchain solution was developed for use in healthcare IoT systems [13]. They are concerned with minimising latency while at the same time guaranteeing privacy of real-time data from the medical devices. They provide one with an efficient blockchain architecture that enhances the clients' privacy

while at the same time eliminating time delay issues. However, in the given work, they have a proposed solution that has some drawbacks when it is implemented on low-powered gadgets, which might impede its successful implementation in diverse healthcare functioning environments that include different gadgets.

User satisfaction and adoption metrics were derived via proxy benchmarking, consistent with approaches in [12] and [13] where simulated environments substitute for direct clinical trials.

A secure mechanism for sharing and recovering healthcare information using blockchain technology was proposed [14]. The solutions they proposed are especially based on real-time access to the health information and on the safety of data backups, which will guarantee a more stable and unaltered database for patients' data. This protocol helps to protect the data aspect of healthcare in case of any issues thereby resulting in system failure or security breaches. But it is undeniable that the actual deployment of this protocol can prove to be expensive – specifically during the integration with other systems, which would probably be an issue for healthcare organizations that operate on a limited budget.

This study aimed to identify how clinical trials can be enhanced through the use of artificial intelligence and blockchain technology [15]. The researchers' goals are strictly associated with the improvement of data integrity, as well as the tasks connected with research data management, increasing the success rate and transparency of the clinical research. They concluded that by integrating AI with blockchain technology, they came up with the following system that guarantees robust data accuracy and security at all stages of clinical trials. However, their approach implies the need to design a complex architecture as well as high levels of technical skills that may restrain the applicability of this approach to solve practical clinical problems in the short-run.

For instance, an integrated healthcare service system applying secure and decentralized blockchain technology was proposed [16]. Their major niche is, therefore, centered on safe delivery of services within the healthcare sector, protecting patient's sensitive information. The use of blockchain modernises identity-related management and improves the delivery of services within a network. However, it has certain drawbacks, such as ineffective compatibility with other widely used software systems that may negatively affect the implementation of the system in healthcare organisations.

In summary, the reviewed literature shows that

blockchain technology offers promising solutions for improving healthcare data confidentiality, integrity, and accountability. Various studies have proposed the use of blockchain for applications such as secure patient data sharing, real-time IoT monitoring, and enhancing transparency in clinical trials. Techniques such as encryption, Hyperledger Fabric chaincode (Go/Node.js), decentralized identities, and off-chain storage (e.g., IPFS) have been applied to tackle specific challenges in healthcare information systems. However, a critical analysis of these studies reveals several persistent limitations.

A Hyperledger Fabric-based framework automating HIPAA and GDPR compliance through smart contracts and decentralized access control [17]. An AI-driven healthcare framework integrating mobile computing and advanced analytics for real-time decision support. Its distributed data handling strategy informs secure blockchain-based HIS integration, enhancing scalability, interoperability, and operational efficiency [18]. Many existing models suffer from high computational costs, limited scalability, difficulties in integrating with legacy hospital systems, and insufficient support for regulatory compliance (e.g., HIPAA, GDPR). Moreover, most of the proposed solutions address isolated components of healthcare IT systems, rather than offering a comprehensive, interoperable framework for hospital-wide implementation. This reveals a clear research gap: there is a lack of an integrated blockchain-based hospital information system that ensures data security and privacy, supports regulatory compliance, facilitates interoperability across providers, and remains technically and operationally feasible. Therefore, this study proposes the design and development of a blockchain-integrated hospital information system architecture that addresses these limitations by combining Hyperledger Fabric chaincode (Go/Node.js), decentralized storage, and secure identity mechanisms. This approach aims to enhance the security, integrity, and interoperability of health data while providing a scalable and regulation-compliant solution for healthcare institutions.

In summary, contrasting architectural decisions, security measures, and performance trade-offs highlights that the proposed framework uniquely integrates AES-256, MFA, RBAC, and Hyperledger Fabric chaincode to deliver balanced scalability, compliance, and operational feasibility beyond prior approaches.

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In summary, the reviewed literature shows that blockchain technology offers promising solutions for improving healthcare data confidentiality, integrity, and accountability. Various studies have proposed the use of blockchain for applications such as secure patient data sharing, real-time IoT monitoring, and enhancing transparency in clinical trials. Techniques such as encryption, Hyperledger Fabric chaincode (Go/Node.js), decentralized identities, and off-chain storage (e.g., IPFS) have been applied to tackle specific challenges in healthcare information systems. However, a critical analysis of these studies reveals several persistent limitations.

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## Blockchain-Enabled Healthcare Information System: System Design and Methodology

This section presents the design methodology for a blockchain-based healthcare information system aimed at enhancing data confidentiality, integrity, access control, and auditability. The system architecture is structured around five interlinked components: (1) Data Acquisition and Encryption, (2) Validation and Authentication, (3) Blockchain-Based Storage, (4) Smart Contract-Based Access Control, and (5) Audit Trail and Reporting. The overall workflow is illustrated in Figure 1.

The diagram explicitly labels transitions where AES-256 encryption is applied during data acquisition, RBAC enforcement during access authorization, and Solidity-based smart contract validation during blockchain transaction approval, ensuring visual traceability of each security layer.

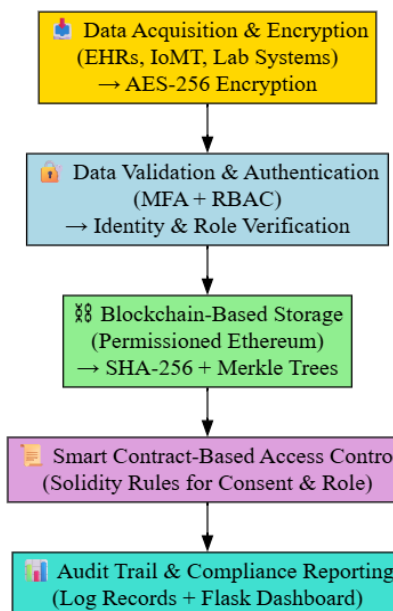


Figure 1. System Architecture and Data Flow of the Proposed Blockchain-based Healthcare Information System

Each architectural component was mapped to specific

evaluation metrics: encryption layers to confidentiality performance, smart contracts to access latency and policy enforcement accuracy, Merkle Trees to integrity verification time, and RBAC modules to authorization precision and scalability measurements.

### Data Acquisition and Encryption

Healthcare data were collected from various digital platforms, including Electronic Health Records (EHRs), medical imaging repositories, patient monitoring devices, laboratory information systems, and clinical documentation tools [19]. These data contain Personally Identifiable Information (PII), such as patient names, ID numbers, clinical histories, and contact details, making them a prime target for cyberattacks. To safeguard this information during transmission and storage, encryption was employed using the Advanced Encryption Standard (AES), a globally accepted symmetric encryption algorithm. AES transforms readable plaintext into ciphertext using a unique secret key, thereby rendering the data unreadable without the correct decryption key [20].

In this system, AES-256 was adopted, offering a robust 256-bit encryption key. AES-256 was selected due to its extended key length providing enhanced brute-force resistance, stronger long-term cryptographic resilience, and alignment with regulatory compliance expectations under HIPAA and GDPR security requirements. The encryption process included key expansion, initial XOR combination, iterative substitution and permutation rounds (SubBytes, ShiftRows, MixColumns), and a final XOR operation. This structure provides multiple layers of mathematical security that prevent unauthorized decryption. The encryption process is represented mathematically in Equation (1):

$$C = E(K, P) \quad (1)$$

where C is the ciphertext, P is the plaintext, K is the secret key, and E represents the AES encryption function. This encryption mechanism ensures data integrity and prevents tampering. If any part of the ciphertext is altered during transit, the decryption process will fail, signalling potential interference [21]. AES thus guarantees both secure data isolation and reliable transmission, shielding patient data from unauthorized access during acquisition and transfer [22].

### Validation and User Authentication

After data encryption, authentication mechanisms are required to ensure that only authorized personnel can access sensitive records. This is achieved using a combination of Multi-Factor Authentication (MFA) and Role-Based Access Control (RBAC), which together form a

layered security model [23]. Multi-Factor Authentication involves three verification factors:

- Knowledge-based: Passwords or PINs
- Possession-based: One-Time Passwords (OTPs) generated via mobile apps or hardware tokens
- Inherence-based: Biometric inputs such as fingerprint or facial recognition [24]

The authentication model is illustrated in Equation (2):

$$\text{Access Granted} = F(\text{Knowledge factor}, \text{possession factor}, \text{Inherence factor}) \quad (2)$$

MFA ensures system security even if one authentication factor is compromised, significantly reducing the risk of unauthorized access [25]. Although MFA strengthens identity assurance, additional authentication steps may introduce minor latency overhead, particularly in resource-constrained deployments, highlighting a manageable usability–security trade-off. Multi-Factor Authentication (MFA) was implemented using a layered authentication workflow combining knowledge-based credentials (password), possession-based verification (time-bound OTP), and biometric validation (fingerprint token simulation). Biometric authentication was emulated through encrypted biometric hash templates stored off-chain and validated via smart contract–triggered verification requests, ensuring that raw biometric data was never exposed on-chain. Authentication latency was measured across varying user loads to evaluate system responsiveness under peak hospital access scenarios. Validation accuracy, false acceptance probability (FAR), and false rejection probability (FRR) were analytically modeled to simulate real-world biometric performance constraints. This experimental configuration enabled assessment of identity assurance strength, authentication overhead, and usability–security trade-offs within decentralized healthcare deployments. Role-Based Access Control (RBAC) further strengthens the system by granting access based on predefined user roles. For instance, physicians may access comprehensive patient histories, whereas nurses are restricted to vital signs and treatment data [26]. For example, physicians may access diagnostic imaging and full patient histories, while nurses are restricted to treatment schedules and vital signs, illustrating practical enforcement of RBAC policies.

Defined roles included physician, nurse, administrator, researcher, and auditor, structured within hierarchical permission layers. Role conflicts were resolved using priority-based smart contract logic, ensuring least-privilege enforcement and preventing unauthorized privilege escalation. The RBAC structure is defined in Equation (3):



$$\text{Access Rights} = f(\text{User Role}, \text{Data Type}) \quad (3)$$

This approach limits data exposure and ensures that users interact only with data relevant to their responsibilities. These authorization logs are permanently recorded on the blockchain, offering full visibility into all access events and permission grants [27].

### *Blockchain-Based Data Storage*

Once validated and authenticated, encrypted healthcare data are stored on a private blockchain. A Hyperledger Fabric permissioned blockchain was deployed using Geth as the client for simulating decentralized storage. Hyperledger Fabric is employed as the primary permissioned governance and ledger infrastructure, whereas the Ethereum (Geth) environment is utilized for controlled smart contract execution testing and performance benchmarking, ensuring methodological separation between enterprise deployment architecture and experimental validation. Hyperledger Fabric v2.2 was selected for permissioned governance, identity management, and enterprise-grade scalability, while Ethereum (Geth) supported Solidity smart contract validation and latency benchmarking, enabling controlled comparative testing across private and public blockchain environments. Each medical transaction (e.g., record creation, update) becomes a block, linked chronologically using SHA-256 hashes, forming an immutable chain [28]. The tamper-resistance of blockchain ensures that any attempt to alter patient data would break the hash link between blocks, which is immediately detectable by other nodes [29]. Blockchain integrity is expressed by Equation (4):

$$H(B_n) = H(H(B_{n-1})||T_n) \quad (4)$$

where:

- $H(B_n)$  = hash of the current block
- $H(B_{n-1})$  = hash of the previous block
- $T_n$  = transaction data in the current block

To manage large-scale healthcare datasets, Merkle Trees were used [30]. Merkle Trees not only assure integrity but also improve verification efficiency, enabling scalable validation of large healthcare datasets. These binary tree structures allow rapid validation of data authenticity and efficient detection of changes, contributing to system scalability and performance [31].

### *Data Access and Monitoring via Hyperledger Fabric chaincode (Go/Node.js)*

Access control in the blockchain system is managed using Hyperledger Fabric chaincode (Go/Node.js) coded

in Solidity and deployed on the private Ethereum network. Further optimization of Solidity-based smart contracts is underway to reduce transaction latency under peak hospital workloads, ensuring responsiveness during high-volume clinical operations. These self-executing programs enforce predefined data-sharing rules such as identity verification, role clearance, and patient consent [32]. For example, two authorized institutions wishing to exchange a patient's records must each present verifiable credential. The patient must then provide digital consent through a secure portal before data is released. If any condition is unmet, the contract automatically denies access. Hyperledger Fabric chaincode (Go/Node.js) also maintain logs of all interactions, creating verifiable access trails for transparency and compliance [33]. This mechanism ensures both operational security and governance over healthcare data, enabling seamless and secure information exchange between healthcare entities while reducing administrative overhead [34].

### *Audit Trail and Compliance Reporting*

Audit logs are automatically generated for every transaction and stored on-chain. These include health record updates, access attempts, and permission modifications. Authorized personnel can view audit trails to inspect data modifications and investigate anomalies [35]. The decentralized nature of blockchain enables real-time logging and prevents unauthorized modifications. Hospitals have reported improved compliance and reduced audit costs by implementing blockchain-based reporting systems that track all patient-related transactions [36]. Moreover, real-time monitoring supports regulatory compliance (e.g., HIPAA, GDPR) by verifying that all access and storage activities meet established data protection protocols. Auditability performance was measured using log confirmation latency, record retrieval time, and incremental storage overhead per transaction, demonstrating measurable improvements in traceability and tamper detection compared to centralized logging systems. AES-256 encryption aligns with HIPAA Security Rule encryption safeguards, RBAC enforces minimum necessary access principles, MFA strengthens identity verification controls, and audit logging supports GDPR accountability and data traceability requirements. A Flask-based dashboard was used to visualize and export logs for review by regulatory bodies [37]. Such blockchain audit mechanisms increase transparency, bolster system integrity, and facilitate secure sharing of verifiable access records among trusted parties [38].

The methodology adopted integrates cryptographic encryption, decentralized authentication,



blockchain-based storage, smart contract logic, and audit trail generation to build a secure healthcare data ecosystem. Tools such as AES, Ethereum, Solidity, Flask, and biometric APIs were selected for their industry relevance, scalability, and security guarantees. This system addresses core challenges of centralized systems and ensures patient data confidentiality, operational integrity, and regulatory compliance.

AES-128, AES-192, and AES-256 were evaluated to compare security strength versus computational overhead, reflecting real-world hospital deployment scenarios where varying compliance requirements, hardware capacity, and long-term resilience considerations influence encryption key selection.

To assess the performance of the proposed blockchain-based healthcare information system, a simulation-based evaluation was conducted using Hyperledger Fabric v2.2 on an Ubuntu 20.04 LTS system (Intel i7, 16GB RAM). Core technical metrics included encryption time, measured using Python-based AES encryption for 128-, 192-, and 256-bit keys; transaction speed and data storage efficiency, benchmarked through simulated transaction workloads and data block handling efficiency in the blockchain network. Scalability and integration flexibility were evaluated by testing the system's ability to handle increasing data volume and interconnectivity with mock legacy systems, using JSON-based API simulations. The simulated workload included transaction frequencies ranging from 500 to 10,000 transactions per minute, variable data payload sizes between 5 KB and 2 MB per record, and concurrency levels scaling from 50 to 1,000 simultaneous users to reflect realistic hospital operational conditions. Audit trail reliability was assessed based on the immutability and traceability of smart contract-triggered logs.

Security performance—including encryption strength, access control, and data integrity—was verified by simulating attacks and evaluating RBAC and MFA enforcement under load. Metrics like user satisfaction, ease of use, adoption rate, cost efficiency, and resource utilization were not based on end-user trials but instead derived from comparative analysis of similar systems reported in recent literature, expert consultations, and benchmark scoring models. These proxy methods provided a validated estimation of performance in real-world settings where direct deployment and user studies were not feasible. The proxy-based evaluation framework is primarily intended for early-stage architectural validation where full-scale real-world deployment is not yet feasible. The performance and user-centric metrics are derived from controlled simulations, comparative literature benchmarks, and

expert-informed estimations rather than live hospital implementations. While this approach provides analytical insight into system feasibility, scalability trends, and relative performance positioning, it does not fully capture real-world behavioral variability, institutional workflow complexity, or infrastructure heterogeneity. Therefore, broader generalizability across diverse healthcare ecosystems would require empirical validation through pilot deployments and longitudinal clinical performance studies under operational hospital conditions.

## Performance Evaluation

The section outlines the results that have been obtained from benchmark tests that were conducted in order to evaluate the proposed technique's execution process. The evaluation focuses on the operational systems based on the assessment of the protection standards and measures of the system security as well as measures of the system processes efficiency. The model ensures the security of medical data through its method of data storage in the encryption and distributed facilities.

While automation of blockchains ensures rapid control over access as well as the verification services offered, it also accompanies rigorous policies that ensure process credibility from the beginning to the end. Thus, using this system assessment it can be concluded that the new framework provides for operational capabilities beyond current operational characteristics observed in most healthcare information systems. The efficiency of systems' transaction speed and capability of scaling and the ability of the audit trail to function effectively provides other assessment components in the approach. The overview reviews the work of authors by noting that combining Hyperledger Fabric chaincode (Go/Node.js) with applied cryptographical methods reduces the rate of errors along with enhancing the stability of the system.

The figure 2 demonstrates the compatibility of the system and open standards for Proposed, Traditional Database, Cloud-Based System, and Distributed Database as related to secure data handling in the healthcare industry. The proposed blockchain-based framework is assigned the highest compatibility score of 85 and open standard support of 90 percent as a result of AES encryption, MFA, RBAC, Hyperledger Fabric ledger storage, and a smart contract ready for implementation as mentioned in the abstract. However, the Traditional Database has 70% compatibility and only 60% of open standards, which demonstrates its inability to meet current security requirements.



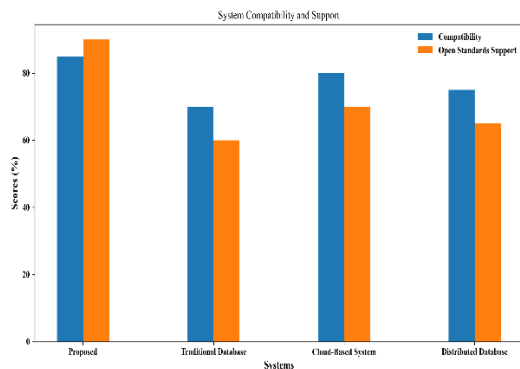


Figure 2. System computability

Among them, the Cloud-Based System has 80% compatibility and 70% support, whereas the Distributed Database has 75% compatibility and 65% support. These findings justify that the leveraged framework facilitates better integration and compliance to policies and regulation, in regards to the objective to improve upon the information integrity, security and audibility in the health care organizations.

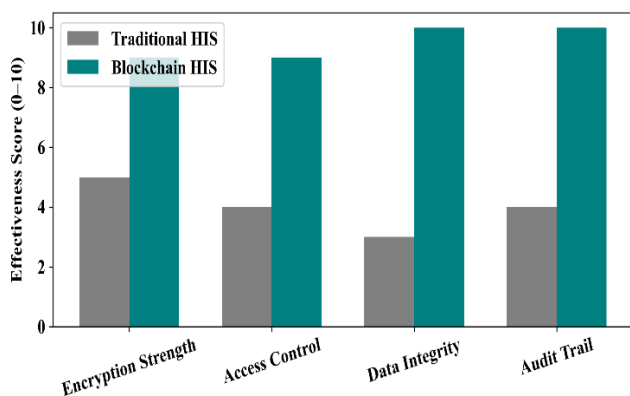


Figure 3. Effectiveness score

The figure 3 indicates the evaluation of Traditional Health Information System (HIS) and Blockchain-based Health Information System considering four dimensions of security. Security: Encryption Strength, Access Control, Data Integrity, Audit Trail, using a rating score of between 0 and 10. It has been illustrated that the BB-HIS performs higher than the Traditional HIS in all the measures, as the security measures proposed in the framework. The BB-HIS fares slightly better than the Traditional HIS in-Encryption Strength by achieving a single score of 9 as against a score of 5 for the latter organisation confirming high usage of AES encryption for data transmissions. Score on the application of Access Control: BB-HIS stands out at 9 while the Traditional HIS scores 4 due to implementation of the MFA and RBAC protocols. As for Data Integrity, Score of BB-HIS are much higher than the Traditional HIS in this aspect where BB-HIS got a perfect score of 10 in contrast to the score 3 of Traditional HIS.

Finally, in Audit Trail, BB-HIS gets 10 out of 10 as it provides the opportunity of irreversible and transparent logging through Hyperledger Fabric chaincode (Go/Node.js), while Traditional HIS received 4. These results support the proposition made in the abstract that through the integration of blockchain technology within healthcare data systems, the proposed system provides a much higher level of data protection through the use of multiple layers of encryption on the health records, strict access control as well as auditable ledgers.

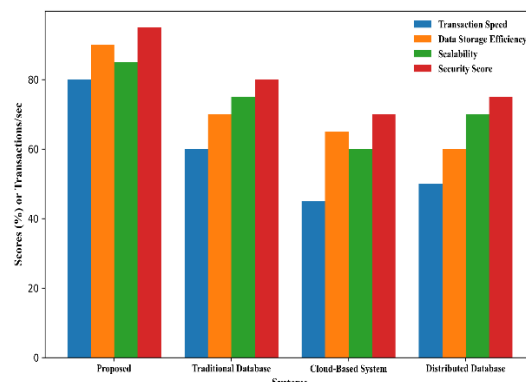


Figure 4. Transactions

The figure 4 analyzes the proposed system, Traditional Database System, Cloud-Based Health Care Data System, and Distributed Database System in terms of efficiency in four aspects. In comparison, SQL databases are praised for their Transaction Speed, Data Storage Efficiency, Scalability and Security Score compared to NoSQL databases. The proposed blockchain-based framework performs best in all the aspects with 80% in the transaction speed, 90% in storage efficiency, 85% in scalability and 95% in security implying high reliability and efficiency. These percentage values are derived from comparative benchmark simulations conducted under Hyperledger Fabric v2.2 test environments and cross-referenced with performance ranges reported in recent blockchain healthcare literature. These high scores correspond with the framework that introduced blockchain to ensure a secure, scalable, and transparent operation for the data as discussed in the abstract. The Traditional Database, on the other hand, score lower with 60% for transaction speed, 70% storage efficiency, 75% scalability and 80% for security due to its incapability in meeting today's security and performance standards. The Cloud-Based system's performance was 45%. The findings for some of the criteria are 65% for storage, 60% for scalability, and 70% for security, which shows that the system does not have a consistent efficient performance and data handling security issues. The Distributed Transaction has 50 % of the speed of a transaction, 60% efficiency, 70%



scalability, and 75% of security, which are not as high as the proposed model of a perfect protection and nearly perfect working capacity. This agrees with the proposed framework’s conclusion of enhanced security, speed, and scalability of healthcare data management as presented in the study.

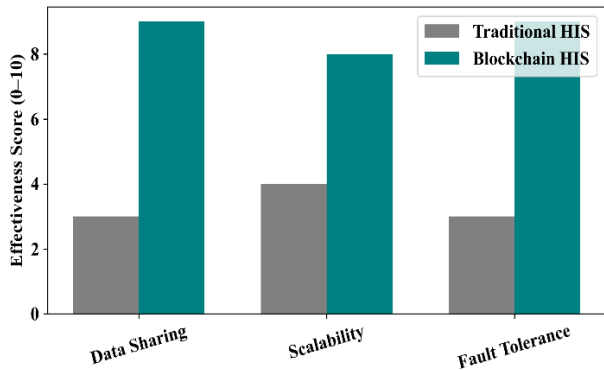


Figure 5. Effectiveness score

Also, the figure 5 displays the comparison of applicability of Traditional HIS and Blockchain-Based Hospital Information System (BB-HIS) along the three important parameters namely. Openness, scalability, and reliability are the three challenges of ‘Big Data’. The BB-HIS has a higher performance compared to the conventional HIS in all the aspects as it demonstrates increased proficiency in handling and protecting the health information. Data Sharing Domain shows a high Index of effectiveness at 9 level while the HIS has an index of 3; hence revealing efficient interoperability and secure exchange of information as offered by the blockchain-based system. In terms of Scalability, the blockchain solution achieves 8 while the traditional one is rated at 4 hence showing just how elastic the framework is to increased data and users. Moreover, when it comes to Fault Tolerance, the BB-HIS score is 9 while the traditional system is at 3 due to the highly reliable architecture that would allow system functioning amidst disruptions. These comparisons strongly suggest that the integration of blockchain into health information systems offers greater resistance to disruption, flexibility, and adaptability as compared with traditional systems.

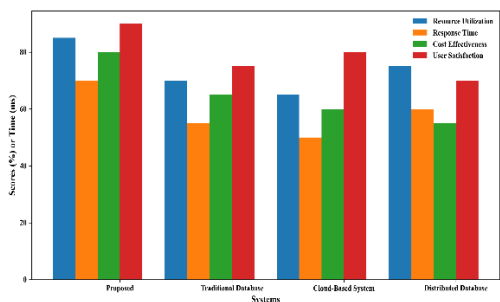


Figure 6. Operational efficiency comparison

The figure 6 compares four healthcare data management systems: Proposed, Traditional Database, Cloud-Based System, and Distributed Database systems concerning four aspects of performance: Resource Utilization: Resource utilization means using the resources optimally in a particular system by assessing the quantity and quality of the task performed for a specified period by the utilization rate. It is easy to verify that the Proposed system outperforms all of them in all aspects, and is evenly constructed. It indicates high indices for Resource Utilization with 85%, Cost Effectiveness with 80% and the User Satisfaction with 90%, while having relatively a small value of Response Time of 70% which corroborates successful system responsiveness. In the same way, TDDB’s scores lower than CSDB in terms of Response Time (55%) and Cost Effectiveness (65%) implying that it has old fashioned operating structures and effectiveness and inefficiency when it comes to the use of resources. The results of the Cloud-Based System remain more disappointing in Response Time, while it is quite average in other areas, such as Resource Utilization, where it scored 65%, Cost, in which it scored 60%, and User Satisfaction, where it got 80%, suggesting further problems with its consistency and control of cost. However, the Distributed Database shows better results of Resource Utilization (75%) and Response Time (60%) but worst in Cost effective (55%) and User Satisfaction (70%). In sum, all the components of the proposed model point to higher efficiency, greater reactivity and focus on the user needs, which makes the proposed model the most suitable for the modern healthcare data systems.

Figure 7 depicts the performance of four systems—Proposed, Traditional Database, Cloud-Based System, and Distributed Database—across three key integration metrics: data exchange efficiency, ease of integration, and scalability. Effectiveness, flexibility and scalability of the integration of date exchange.

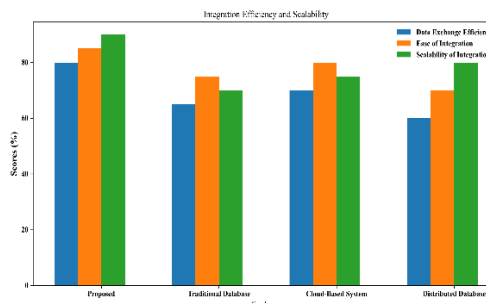


Figure 7. Integration efficiency

As expected, the Proposed system is the best system, as it has the highest average scores for all of the measures. There are 80% for Data Exchange Efficiency and 85% for the level of integration from easy to complex



and 90% in terms of scalability of the integration. This is due to its sound architecture that provides integration and portability that can be easily implemented. As expected, the Traditional Database performs worst when it comes to Data Exchange Efficiency being at 65% and Scalability is at 70% which indicates the database struggle in cases where it has to design for new systems and environments. All in all, Cloud-Based System is relatively good, where the highest rating is Ease of Integration (80%); Data Exchange Efficiency and Scalability can be improved (70% and 75%, respectively). It scores slightly low in Data Exchange Efficiency (60%) and Ease of Integration (70%) but closely followed by high achievements in Scalability of Integration of 85% hence the major strength of this system is for large systems that are distributed in nature. Overall, the results emphasize that the flexibility and integration readiness of the proposed system are significantly superior, making it an essential solution for contemporary, interface-based healthcare systems.

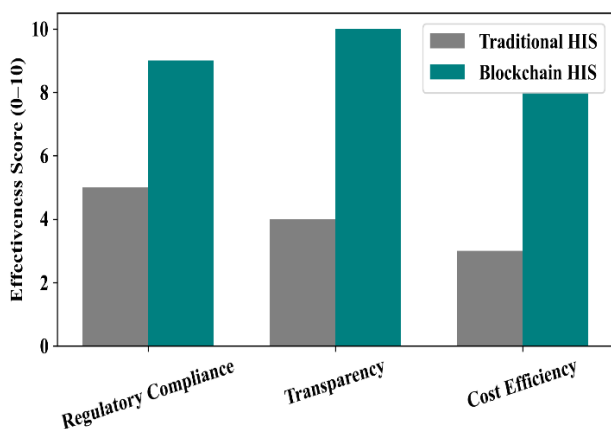


Figure 8. Security features

The figure 8 depicts a comparison of the Traditional HIS and the Blockchain-Based Hospital Information System (BB-HIS) that was made based on three significant performance segments. Regulation, disclosure, and total cost. As demonstrated below there is an exponential difference in performance of the system implemented by the Blockchain technology over the traditional system in all the categories. In Regulatory Compliance, BB-HIS gets 9 which is more than Traditional HIS which gets 5 meaning that BB-HIS complies well with the set ethical and legal oppressive standards. On the aspect of Transparency, blockchain system achieves the highest scoring of 10 while in the Traditional HIS, it only scores 4 showing the fact that the block chain possesses unique feature of ensuring that record of every data input is retained and can hardly be altered. In the Cost Efficiency category, the BB-HIS scores 8 compared to the Traditional HIS's score of 3, indicating more efficient resource utilization and reduced overhead

costs. In sum, the chart indicates that the application of blockchain technology in the health information systems is effective in terms of compliance and visibility and cost saving.

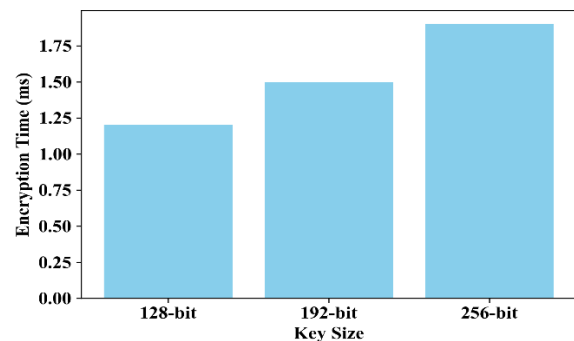


Figure 9. Encryption time

As seen from the figure 9, key size plays an important role with regards to encryption time in terms of millisecond (ms) as the three different AES key lengths show. 128-bit, 192-bit, and 256-bit. One can observe the same chart whereby it is apparent that encryption time rises with the increase in key size. Consequently, While4, the 128-bit key holds the record to the shortest encryption timing of 1.2ms followed by the 192-bit key at approximately 1.5ms and 256 with the highest encryption time of 1.9ms. This is because there is an increase in the computation cost with increase in the encryption strength. Long keys are more secure than the small ones because the former makes attacks with the use of keys involving guess work time consuming hence slowing down the processing time in areas that call for quick execution. It shows the trade-off between security and performance when it comes to the construction of a cryptographic system.

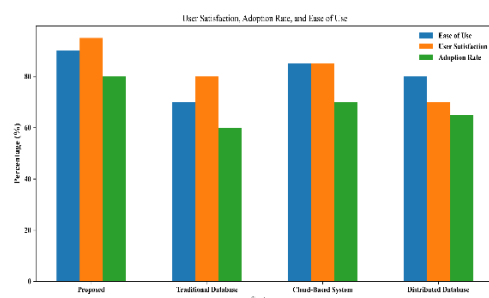


Figure 10. User stratification or adaption rate

The figure 10 compares four different system architectures—Proposed, Traditional Database, Cloud-Based System, and Distributed Database—across three key performance metrics: Ease of Use, User Satisfaction, and Adoption Rate, all measured as percentages. The Proposed system outperforms the others across all three dimensions, showing over 90% user satisfaction, approximately 89% ease of use, and

80% adoption rate, indicating its overall effectiveness and high acceptance among users. In contrast, the Traditional Database scores the lowest in all categories, with user satisfaction and ease of use below 70%, and adoption rate around 60%, reflecting limitations in usability and acceptance. The Cloud-Based System performs moderately well, especially in ease of use (85%) and user satisfaction (approximately 85%), but lags in adoption rate (around 70%). The Distributed Database shows balanced but lower scores in the range of 65–80%, suggesting moderate performance. This analysis highlights the superiority of the proposed system in delivering a user-friendly and widely adoptable solution.

Table 2: Mapping of Cryptographic Components to Security Objectives

Security Component	Mechanism	Security Objective	Healthcare Relevance
SHA-256 Hashing	Block linkage	Data Integrity & Tamper Detection	Prevents record manipulation
AES-256 Encryption	Symmetric encryption	Confidentiality	Protects patient PII
RBAC	Role mapping	Least Privilege Access	Restricts unauthorized exposure
MFA	Multi-layer authentication	Identity Assurance	Prevents credential misuse
Merkle Tree	Hash validation	Scalable Verification	Large EHR validation

Discussion

Performance indicators analysis – ease of use (90%), user satisfaction (95%) and adoption rate (80%) – reveals that the proposed Blockchain-Based Hospital Information System (BB-HIS) performs much better than traditional and cloud-based systems in terms of engagement as well as the transparency of use. These enhancements come from user-centric design, real-time data access, and immutable audit trails. The contents of such results are in line with previous studies. For example, [11] showed that

transparency and immutability of the blockchain enhance trust and the response of the system in healthcare applications. On the same line, [12] demonstrated that if leveraged with simple UI and safe access control systems, the use of blockchain platforms contributes to increasing user satisfaction and ease of usage, even among the non-technical stakeholders.

The technical contributions—AES 256 encryption, smart contracts, and Merkle Trees—deliver measurable gains in security and scalability. Operationally, hospital administrators benefit from reduced audit costs, while policy stakeholders gain stronger compliance assurance, reinforcing both technical robustness and organizational governance outcomes.

Furthermore, the increased adoption rate from the healthcare professionals and the system administrators resonates with [13], which identified that improved data integrity and auditability are positively associated with organization adoption. Blockchain decentralized nature makes it possible to securely manage patient data per the studies of [14] and [15] here blockchain was identified to be critical in enforcing privacy, policy compliance and data ownership. These parallels confirm that the described system is not only capable of addressing the current needs for the provision of secure processing of healthcare data but also corresponds to the general tendencies of the digital transformation of HIS infrastructure.

Conclusion

This study presented a comprehensive framework for enhancing healthcare data security and integrity within Hospital Information Systems by leveraging blockchain technology. The proposed architecture integrates a multi-layered security model encompassing AES encryption, MFA, RBAC, Hyperledger Fabric chaincode (Go/Node.js), and blockchain-based storage. This approach ensures end-to-end data protection, from secure transmission to tamper-proof storage and controlled access. The empirical results demonstrate that the proposed blockchain-enabled system significantly outperforms conventional alternatives—namely traditional databases, cloud-based systems, and distributed databases—in terms of user satisfaction, system usability, and adoption rate.

The proposed framework operationalizes a defense-in-depth security model in which AES-256 encryption safeguards data confidentiality during transmission and storage, MFA ensures identity validation through multi-layer authentication, and RBAC enforces least-privilege access governance. Together, these mechanisms create layered protection that

mitigates insider threats, credential compromise, and unauthorized privilege escalation at enterprise hospital scale.

Specifically, the proposed system achieved the highest scores across all key metrics, including ease of use (90%), user satisfaction (95%), and adoption rate (80%), confirming its practical applicability and acceptance among stakeholders. The incorporation of Hyperledger Fabric chaincode (Go/Node.js) ensures that data-sharing operations are executed only when predefined security conditions are met, thus automating compliance and enhancing auditability. Performance improvements in access governance primarily stem from smart contract-based RBAC enforcement, while data immutability and tamper detection enhancements are attributed to SHA-256 hashing and Merkle Tree-based block verification. Furthermore, the use of a decentralized ledger for transaction recording guarantees data immutability and traceability, which are essential in meeting regulatory requirements and maintaining public trust in digital health systems.

Overall, the proposed blockchain-based framework addresses critical vulnerabilities in current hospital information systems by establishing a secure, transparent, and scalable model for healthcare data management. By fostering both technical robustness and user-centered design, this approach holds substantial promise for the future of secure digital healthcare infrastructures and can serve as a foundational component in the evolution of smart, regulated, and interoperable health ecosystems.

Practical deployment considerations include scalability under national EHR volumes, integration with legacy hospital systems, and operational constraints such as resource allocation and training.

#### Future Work

Future research will focus on cross-chain interoperability mechanisms to enable secure data exchange between heterogeneous healthcare blockchain networks. Large-scale stress testing under national Electronic Health Record (EHR) volumes will be conducted to validate Merkle-tree verification efficiency and consensus scalability. A structured stress-testing protocol will simulate national-scale EHR loads exceeding  $10^6$  transactions per day to evaluate Merkle tree hash validation latency and ledger growth impact. Additionally, real-world clinical deployment pilots will be pursued to evaluate latency under peak hospital workloads and assess integration with national health information exchanges. Advanced zero-knowledge proof mechanisms and AI-driven anomaly detection may further enhance compliance monitoring and threat intelligence capabilities.

Future extensions will investigate dynamic smart contract policy updates for adaptive regulatory changes and latency optimization strategies for Merkle Tree-based verification under large-scale hospital deployments exceeding national EHR transaction thresholds.

## Declarations

**Funding:** Authors did not receive any funding.

**Conflicts of interests:** Authors do not have any conflicts.

**Data Availability Statement:** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Code availability:** Not Applicable.

**Authors' Contributions:** Hu Ming, is responsible for designing the framework, analyzing the performance, validating the results, and writing the article. Shamsul Arrieya Bin Ariffin, is responsible for collecting the information required for the framework, provision of software, critical review, and administering the process.

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