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Utilizing Blockchain Technology for Secure and Efficient Healthcare Data Management Contribution

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Abstract: Present healthcare systems face increasing challenges due to growing complexity, fragmented data management and high operational costs, infrastructures. These limitations obstruct interoperability, compromise data security, and reduce the efficiency of healthcare service delivery. Blockchaintechnology offers a tamper-proof, promising and decentralized framework which enables secure, transparent management of healthcare data. Properties of blockchain technology are: immutability, auditability, interoperability, and decentralized control - enable secure and trustworthy data exchange among healthcare stakeholders. Initially designed for financial applications, blockchain has evolved to support healthcare use cases, including electronic health record management, insurance claim processing, medical device traceability and prescription tracking. There are a number of issues such as: Access control, interloper ability, provenance and data integrity which is improved by blockchain technology. This article presents a comprehensive review of blockchain-based approaches for securing healthcare data, with an emphasis on improving data accessibility and increasing security. It examines key system architectures, consensus mechanisms, access control models, and consensus algorithms used in healthcare applications. Furthermore, the study evaluates widely adopted blockchain platforms such as Hyperledger Fabric, Ethereum. This review highlights the benefits, limitations, and open research challenges associated with blockchain-enabled healthcare systems. Overall, the paper contributes to ongoing research efforts aimed at leveraging blockchain technology to enhance security, efficiency, and trust in healthcare data management.
Keywords: BlockchainTechnology, Decentralized Systems, Secure Healthcare Data Management, Electronic Health Records, Scoping Review.

I. INTRODUCTION

Blockchain technology is known for inherent features, including decentralization, transparency, and anonymization. The success has consequently led to a number of discussions and propositions regarding blockchain applications across a wide range of data-driven areas, including health [5]. According to IBM, 70% of healthcare leaders believe that the highest impact of blockchain in the health domain will be related to clinical trial management, regulatory compliance, and providing a decentralized platform for EHR sharing [2]. Moreover, the global blockchain technology market in the healthcare sector is expected to surpass $500 million by 2022 [2]. While blockchain technology is considered to have the potential to "advance" health information systems [5].The technology has also led to unrealistic propositions, and the current literature lacks any overall views of applications that have been created, tested, and/or put into practice. The present study aims at systematically reviewing, appraising, and synthesizing published peer-review studies in which blockchain has been applied (or suggested to be applied) to enhance processes and services provided within the health domain. In addition to an investigation of the evidence, the study intends to provide an overview of what has been achieved, what is known, and could be directions for future research in this area.

Blockchain is a public and decentralized digital ledger of transactions spread amongst many computers, in such a way that no participant can retrospectively alter any block without similarly rewriting all successive blocks. Each block in the blockchain is cryptographically validated and linked to its immediate predecessor in such a way as to create an extended chain. In essence, blockchain is the record itself. Since each transaction is publicly registered and verified, blockchain offers significant accountability. Once recorded, the information in the blockchain cannot be amended by anyone. This attribute proves the authenticity and immutability of the data. In blockchain systems, data is stored across networks instead of a central database, which increases stability and exposes vulnerability to hacking. Blockchain provides a useful base for creation and competing with conventional business models by facilitating contemporary and innovative business models [3].

Blockchain helps marketers in maintaining medicines that are used in healthcare. In health and pharmaceutical-related areas, blockchain technologies can minimize counterfeit medication by enabling end-to-end tracing of all medicinal products to assist in finding causes for falsification. Blockchain can maintain confidentiality of patient records; as medical histories grow, blockchain records them in tamper-proof, with records that cannot be edited. This decentralized network integrates with the hardware of hospitals across relevant subsystems. Researchers use resources conserved by these devices for computing

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estimates for therapies, medicines, and remedies over a variety of illnesses and disorders [2]. A blockchain is a dispersed ledger network that adds records and does not delete or edit them without a mutual agreement. The value of a blockchain hash is dependent on a cryptographic hash that links newly added information blocks with preceding data blocks. Dispersed ledger architecture intrinsic to blockchain has ensured data processing without a centralized venue; that improves accessibility and accountability for all participants of the network [2,3].

1.1 Blockchain Technology

Blockchain is a decentralized system consisting of nodes that work together and store data, safeguarding confidential information. It facilitates the secure sharing of essential information, organizes related documents within a single secure location. Blockchain enhances the speed of identifying applicants who fulfill trial criteria by offering access to a shared patient database. Theoretically, Blockchain technology is defined as a peer-to-peer network of personal computers that maintain, document data and store. This Peer to peer network promotes secure collaboration, as all participants in the network share and save information and establish a continuous record of their transactions. The most important elements of blockchain are blocks, nodes, and miners. These elements are distributed across multiple computers (Fig.1). Each node updates its version of the blockchain [7].There are different types of blockchain technology such as public, private, hybrid, and consortium, each has benefits and drawbacks Every node in the network adheres to the same protocols and maintains identical records of transactions, enabling value exchange without the need for intermediaries via machine consensus.

Public Blockchain such as Bitcoin, promote decentralization and enhance transparency. It is eliminating the need for centralized data storage. They require systems for authenticating data. Private blockchains function within controlled settings and are overseen by a single entity [2,7]. They retain some Peer to Peer characteristics; their scope is more restricted and involves known participants. Hybrid blockchains contain private and public blockchains.

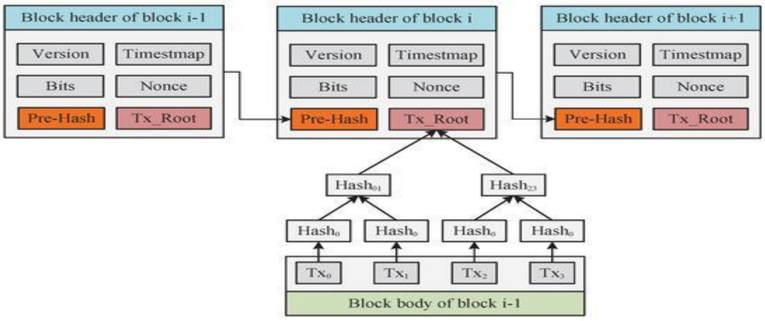

Fig.1. Structure of Blockchain [7]

II. BLOCKCHAIN IN HEALTHCARE DOMAIN

The healthcare sector heavilyfocuses on data and skilled personnel, making access to, modification of, and trust in data essential for its operations. Healthcare activities include solving health problems, making clinical decisions, and evaluating care, all requiring collaboration among a multidisciplinary team of health professionals [2]. This collaboration delivers the best health outcomes with the latest knowledge and technologies.

The healthcare sector must establish strong collaborationwith educational institutions to provide structured training opportunities for students and ensure the development of essential skills. In equivalent, healthcare organizations should collaborate with research and engineering institutions to gain access to specialized expertise and resources required for clinical trials and advanced medicalresearch. Such interdependence necessitates efficient mechanisms for patient data sharing and consent management, while simultaneously ensuring the confidentiality and security of sensitive patient information. Overall, the effective functioning and continuous advancement of healthcare systems depend on robust collaboration with academic and research institutions.

To enable secure data sharing while preserving patient privacy, several critical challenges must be addressed, including access control, data provenance, data integrity, and interoperability. Traditional access control mechanisms rely on trust-based relationships between data owners and centralized storage entities that enforce access policies. Interoperability facilitates seamless communication among heterogeneous healthcare information systems and devices, thereby improving data accessibility and clinical collaboration. Data provenance ensures traceability by maintaining a verifiable record of data origin and modification history, enhancing auditability and transparency in electronic health record (EHR) systems. Data integrity

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reflects the accuracy and reliability of healthcare data, ensuring that information remains consistent and meets predefined quality standards.

Healthcare institutions face rising demand for real-world data from industry and research organizations, but unauthorized data sharing and publicized breaches damage trust. Additionally, malpractices in healthcare, such as counterfeit drugs and skills exploitation, further undermine confidence. This situation calls for new approaches [2]. Blockchain technology offers solutions with its attributes of decentralization, distribution, and data integrity. It can enhance interoperability, information sharing, access control, and data integrity among stakeholders, helping to establish a new framework for rebuilding and sustaining trust in the healthcare system (Fig.2).

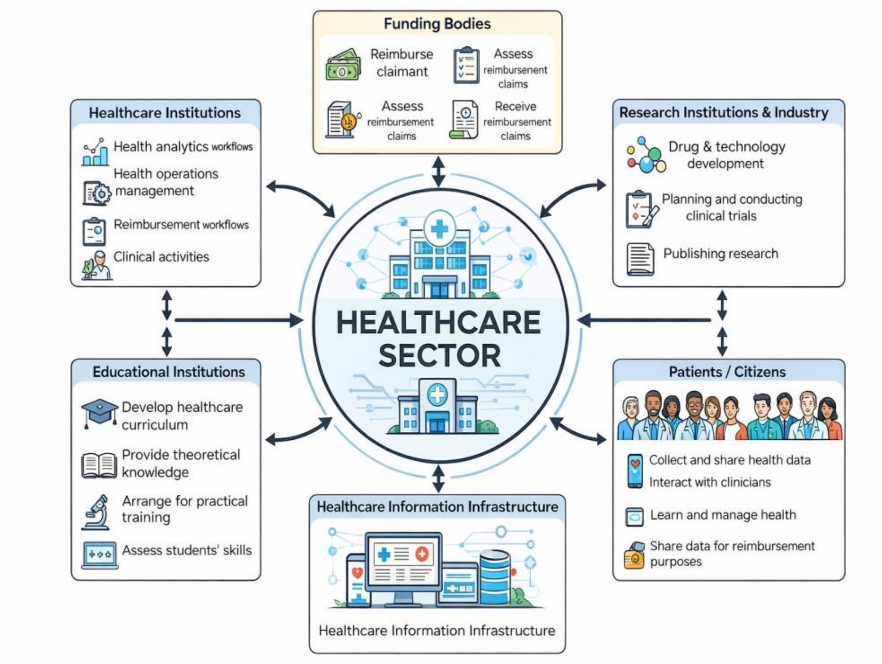

Fig.2. Different Healthcare Sector

2.1 BlockchainApplications for Healthcare

Blockchain technology is part of the healthcare industry, where specific challenges need to be overcome. The first major obstacle to adopting this high-end technology by medical facilities is a lack of expertise. Applications of blockchain remain in their infancy stage, though there are significant applications of blockchain for healthcare.

TABLE I

BLOCKCHAIN APPLICATIONS FOR HEALTHCARE

Sr. No.	Applications	Description	References
1.	Individual patient's information	Before and after clinical study phases, patient information and health data are generated, including blood tests and wellness polls. Healthcare providers check data validity using records stored on a Blockchain system, which uses cryptographic techniques for secure data sharing.	[3,8]
2.	Transparency and safety	It enhances safety, transparency and allows doctors to focus on patient care. It enables efficient data sharing among healthcare providers, thereby improving diagnostic processes and treatment strategies.	[12]
3	Analyses of a particular procedure	Researchers can conduct large-scale analyses of clinical procedures across diverse patient populations using securely verified data access. Blockchain technology enables pharmaceutical organizations to collect real-time and reliable patient data to support personalized medication strategies while streamlining pharmacy operations.	[13]

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4.	keeping Health record	Blockchain technology enhances healthcare record-keeping by enabling secure data sharing, efficient management of medical records and insurance processes, and streamlined administrative operations. It provides patients with transparent access to their historical health information while ensuring data privacy, integrity, and authenticity.	[5]
5.	Validation	Communications in a blockchain are validated through consensus algorithms and secured using cryptographic techniques, including encryption and digital signatures. The aims of the healthcare industry to leverage this technology to deliver more secure, cost-effective, and efficient healthcare services.	[4]
6.	Trial for hospital	Blockchaintechnology enhances the reliability of clinical trial data by mitigating inconsistencies, preventing tampering. Thefacilitates healthcare market analytics as well as secure (end to end)medicine lifecycle management from production to consumption.	[5,6]
7.	Display Original information	The Blockchainsystem ensures medication quality by showing its origins and details of manufacturer. Blockchain systems increase protection, healthcare and lead to market changes.	[3,4]
8.	False Content Identify	Blockchain improves data transparency and integrity using supporting verifiable clinical study validation, public auditability of clinical trials, secure and controlled access to electronic health records.	[5]
9.	Monitoring of the Patient	A Blockchain system helps medical professionals access equipment and monitor patients more effectively. It combines Blockchain with IoT to increase supply chain responsiveness and transparency in healthcare.	[16,3]
10.	Maintain an accurate Record of the financial statements in hospitals	Accurate financial records are essential in bookkeeping. Blockchain companies streamline accounting and reporting, helping patients complete paperwork early to save time. We can learn about Blockchain's risks and benefits in healthcare.	[3,4]
11.	Improves Patient safety	Blockchain improves patient safety in healthcare by ensuring medication validity, drug traceability, and enabling secure data sharing. It helps prevent counterfeit drugs and allows doctors to easily access medical records for better diagnosis.	[14,15]
12.	Minimize data transformation time and cost	Blockchain networks reduce time and costs for data transformation, improve medical credential verification, ensure patient anonymity, and facilitate valuable, privacy-respecting data sharing in healthcare.	[3,5]

III. TECHNICAL CONCEPT OF BLOCKCHAIN

3.1 Types of Blockchain

Blockchain can be divided into four types: public, private, consortium, and hybrid. Public blockchains are open and transparent but slower. Private blockchains are controlled by one organization for better privacy and speed [7]. Consortium blockchains are managed by multiple trusted organizations. Hybrid blockchains mix both features for flexibility and security.

TABLE II

DIFFERENT TYPES OF BLOCKCHAIN

Types of Blockchain	Access Control	Ownership / Governance	Key Features	Typical Use Cases
Public Blockchain	Open to everyone	Fully decentralized	High transparency, immutability, low trust requirement, slower transactions	Crypto currencies, public records
Private Blockchain	Restricted access	Single organization	High privacy, fast processing, controlled participation	Healthcare data management, enterprise systems
Consortium Blockchain	Limited to selected members	Group of organizations	Shared control, better security than public, scalable	Healthcare networks, banking, supply chains
Hybrid Blockchain	Partially public and private	Mixed governance model	Selective transparency, flexible access, enhanced privacy	Healthcare, government systems, enterprise applications

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3.2 Platform/ Framework of Blockchain

Ethereum was utilized in eleven publications (28%), Hyperledger Fabric in four (10%), and Exonum in one case (4%) of the thirty-nine included ones (Fig. 3). Fourteen studies reported that a new blockchain has been developed for their particular concept. In eight cases, the study did not mention a platform or framework for a particular concept being presented in the paper (Fig.3)[2].

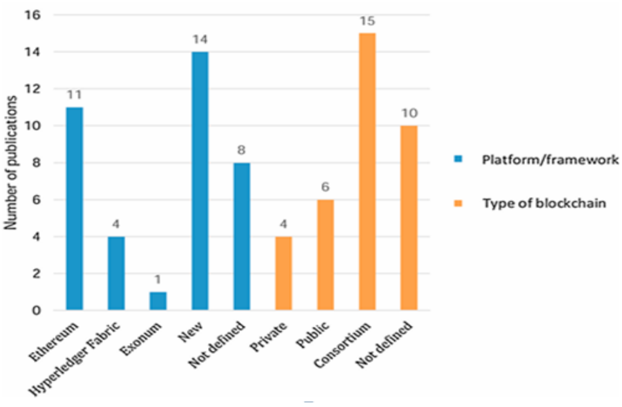

Fig.3. Platform/framework of Blockchain [2]

3.3 Consensus Algorithm

A key component of blockchains is the method by which data entries are accepted onto the distributed ledger via a distributed consensus protocol that validates the data entries. A number of consensus protocols have been proposed and implemented; amongst these, the three most commonly used are illustrated in Table 2 and discussed below.

TABLE III

COMPARISON OF CONSENSUS MECHANISMS

Property	Proof of Work (PoW)	Proof of Stake (PoS)	Practical Byzantine Fault Tolerance (PBFT)
Node Participation	Open and permission less; any node can join the network	Open participation based on stake ownership	Permission network with pre-approved nodes
Energy Requirement	Very high due to intensive computational mining	Moderate, as block validation depends on stake	Low, since no mining or heavy computation is involved
Fault / Attack Tolerance	Secure if malicious nodes control less than 25% of total computing power	Secure as long as attackers hold less than 51% of total stake	Can tolerate up to 33.3% faulty or malicious replicas
Validation Basis	Computational power (hashing)	Amount of crypto currency staked	Message exchange and voting among replicas
Typical Use Case	Public cryptocurrencies	Energy-efficient public blockchains	Enterprise and consortium blockchains
Example Platform	Bitcoin	Peercoin	Hyperledger Fabric

Proof-of-Work (PoW) is a consensus method used in blockchain technology, mainly associated with Bitcoin. In a PoW system, miners compete to solve a hard puzzle. They try to find a hash for a block that is lower than a set value. The first miner to succeed confirms the transactions in the block and receives a reward. A significant drawback of PoW is its high power consumption, similar to the electricity usage of a small country due to Bitcoin mining [9].

Proof of Stake(PoS)is a scheme where an approving node is chosen based on the amount of currency each node holds. This can create an unfair advantage for wealthier nodes. Various hybrid versions of PoS combine node stake with randomness to select the approving node. Ethereum, the second-largest cryptocurrency, plans to switch from PoW to PoS[10].

Practical Byzantine Fault Tolerance (PBFT) uses a Byzantine agreement protocol and requires all nodes in the network, limiting its use in public blockchains. PBFT has three phases: pre-prepared, prepared, and committed, needing two-thirds of votes from nodes. It is used in HyperledgerFabric[11,2].

IV. LIMITATIONS

Blockchain technology offers tremendous competence for enhancing many aspects of how we provide patient care; however, we need to overcome several obstacles to the widespread use of blockchain in the healthcare industry so that we adopt and implement blockchain technology in the healthcare industry.

The most significant obstacle is the performance and scalability of blockchain while using blockchain for healthcare solutions. Blockchains built using consensus algorithms like proof-of-work (PoW) experience remarkable limitations with respect to their ability to scale, resulting in high latency, limited throughput, and a huge amount of computing resources that are required to maintain immediate access and continuous updates to healthcare records. Apart from concerns relating to performance and scalability, blockchain also presents a significant level of technological complexity to the healthcare industry and there is a lack of competence with the requisite skills to build blockchain-based healthcare solutions. While establishing blockchain-based healthcare solutions, we require a good understanding of cryptography, distributed computing, and smart contract development; however such skill sets are rare among organizations in the healthcare sector.

In addition to this, the operational cost of using a PoW-based blockchain is far above the ground, leading to concerns about the environmental sustainability of PoW-based blockchains due to large amounts of energy consumption to operate PoW-based blockchainnetworks. Moreover, the healthcare industry relies heavily on efficient use of energy to operate, so using PoW-based blockchains to manage healthcare data is not feasible.

Fourth, regulatory compliance and data privacy issues in the healthcare industry are also a significant obstacle. Although blockchain is designed to provide an immutable chain of records, all data in healthcare are extremely sensitive and comes with significant privacy restrictions imposed by regulatory agencies that require prior consent and data protection for patient records. Thus, placing personal health records on a blockchain creates a conflict with regulatory compliance requirements that only allow for the modification or deletion of data with prior consent.The fifth and final limitation is that the integration of current health IT with established blockchain platforms is not well-established. Blockchain and existing legacy EHR, mHealth device integrations, and HIS integrations will all require standardized data formats/communication protocols that are still evolving.

Finally, governance and standardization issues will continue to persist, especially for permission or consortium blockchains. Creating a clear trust framework, access control policies, and defining the roles of each stakeholder, such as hospitals, insurance companies, researchers and regulators, is complex and has not yet been established.

V. CONCLUSIONS

It finds innovative applications in healthcare due to its inherent cryptographic security and decentralization. It enhances the security of patients' electronic medical records, monetizes health information, enhances interoperability between different healthcare organizations, and combats counterfeit medicines. Several areas in the healthcare sector can be revolutionized by blockchain technology. For instance, smart contracts-based healthcare digital agreements are one of the most critical usages of blockchain. Smart contracts are supposed to cut down costs by eliminating intermediaries from the payment chain.

Blockchain's potential in the healthcare industry is closely linked to the ecosystem's adoption of associated cutting-edge technology. Clinical studies, health insurance, system tracking, and medication tracing are all included. Hospitals can document their services on a blockchain network for the duration of their existence by using device tracking. Blockchain technology has strong potential to transform healthcare by providing secure, decentralized management of medical data. It improves the protection and interoperability of electronic health records, enables health data monetization, and helps prevent counterfeit medicines. Key applications include smart contract–based healthcare agreements that reduce costs by removing intermediaries, along with support for system tracking, insurance processing, medicine traceability, and clinical trials. By enabling efficient device tracking and better patient history and insurance management, blockchain facilitates faster clinical decision-making and optimized data handling, ultimately improving healthcare services for both patients and providers.

VI. FUTURE WORK

In the coming years, existing challenges to blockchain adoption in healthcare can be addressed to enable scalable and sustainable implementations. Key research directions include the development of energy-efficient and scalable consensus mechanisms, such as Proof of Stake (PoS) and Practical Byzantine Fault Tolerance (PBFT), as well as the adoption of off-chain and hybrid storage architectures to improve scalability and regulatory compliance. Standardized frameworks and interoperable APIs are essential for integrating blockchainplatforms with existing healthcare systems. Further research on advanced privacy-preserving and access control techniques, including attribute-based access control and zero-knowledge proofs, is necessary to protect patient data while enabling authorized sharing. Finally, large-scale pilot deployments and studies on regulatory, legal, and ethical frameworks are required to assess the practical feasibility and responsible adoption of blockchain technology in healthcare.

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