International Journal of Basic and Applied Sciences, 14 (4) (2025) 773-785

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/6xkkem36
Research paper

Exploring Blockchain Technology: An Introductory Perspective on Its Role in Healthcare

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Received: June 20, 2025, Accepted: July 29, 2025, Published: August 28, 2025

Abstract

Emerging technologies such as Blockchain (BC) are increasingly being leveraged across various industries, including healthcare, to introduce innovative solutions. In the healthcare sector, blockchain facilitates the secure storage and sharing of patient data among multiple stakeholders, such as hospitals, diagnostic centers, pharmaceutical companies, and medical professionals. Blockchain-based applications in medicine can accurately detect critical errors, including potentially hazardous ones, thereby enhancing the safety, efficiency, and transparency of medical data exchange. Traditional healthcare systems rely on multiple centralized databases to store patient records, often leading to data fragmentation, interoperability challenges, and security risks. Blockchain's distributed and immutable ledger can address these concerns by providing a unified, tamper-proof source of truth for healthcare data. This research begins by conducting a detailed analysis of blockchain technology, emphasizing its core principles, including decentralization, immutability, and cryptographic security. Additionally, the study examines various applications of blockchain in healthcare, such as managing patient records, tracking supply chains, and overseeing clinical trials. It highlights the potential advantages of blockchain, such as improving transparency, reducing costs, and enabling patients to have greater control over their personal health information. The study aims to provide a comprehensive overview of the latest research trends in blockchain-based healthcare solutions, addressing current advancements, challenges, and potential future applications. By thoroughly exploring the evolving landscape of blockchain technology in healthcare, this research seeks to offer valuable insights into its ongoing development and impact.

Keywords: *Blockchain; Healthcare; Challenges; Applications; Systematic Review.*

1. Introduction

One major issue with today's healthcare systems is the high expense of maintenance and management [1]. There are many different parts to the healthcare system, including patients, researchers, practitioners, support workers, managers, and doctors [2]. The consequent difficulty in classifying and managing patient data is substantial [3,4]. diverse healthcare domains have diverse data structures and workflows, which makes this task much more difficult. This is why it's so problematic that different areas of healthcare do not effectively share patient records [5]. ‘Blockchain technology’ (BCT) offers invaluable solutions for the healthcare and pharmaceutical industries, aiding in product oversight and combating counterfeit medications. Through blockchain, the entire supply chain of medicines can be transparently traced, facilitating the detection of any falsification and its root causes. Additionally, BC ensures the confidentiality and integrity of patient records, securely storing medical histories in an unmodifiable format. This decentralized network can seamlessly integrate with existing commodity hardware in hospitals, optimizing resource utilization. Researchers can leverage these resources to compute estimates for therapies, medicines, and remedies for various illnesses and disorders, thereby driving innovation and efficiency in healthcare delivery [6] [7].
The increasing digitization of medical treatment has led to an increased awareness of concerns regarding the safe storage and access of patients' medical records, as well as ownership and medical data from connected sources [8] [9]. A solution that is advocated for tackling notable barriers that are encountered by the healthcare industry is blockchain. Some examples of these concerns include the secure sharing of health records and the adherence to data privacy rules [10] [11]. There is a specific kind of database known as blockchain, which may

be administered by a network of verified members or nodes [12]. Blockchain can hold immutable information blocks that can be strongly traded without intervention from third parties [13]. The storage and registration of data is accomplished using cryptographic signatures and the implementation of consensus methods, both of which are significant enablers in their application [14]. Memory retention is a fundamental goal for the use of the BCT, notably in the healthcare industry [15], which is susceptible to the widespread exchange and dissemination of a substantial amount of data [16]. BCT can transform the structure of a healthcare network, decentralizing data appendages. Through blockchain, patients can integrate themselves into an ecosystem that bolsters security, confidentiality, and data interoperability [17]. In essence, blockchain is a system designed to secure transaction data and monitor any alterations or transfers of data across different levels. Implementing such a system can enhance the security of development processes [18]. This research proposal aims to explore the breadth of BC implementation and investigate its potential applications in healthcare solutions.

The structure of this paper is as follows: Section 2 outlines the survey of the literature, while Section 3 provides a summary of the background and fundamentals of BCT. Section 4 explores the key challenges and potential opportunities in research. Finally, Section 5 concludes the paper and offers recommendations for future research endeavours.

2. Literature review

Several recent studies have scrutinized IoT, blockchain, and related topics from technological standpoints. Several efforts have been made to generate review articles on this research subject.

Ghosh PK et.al [19] offered a comprehensive overview of existing research on BC applications within the healthcare sector. Through an evaluation of 144 articles, it examines the significance and constraints of employing BCT to enhance healthcare operations. The objective is to showcase the potential utility of this technology while also identifying the challenges and potential areas for future exploration in healthcare-related blockchain research. The paper commences with an in-depth exploration of blockchain and its characteristics. Subsequently, it conducts an extensive literature review of the chosen articles, highlighting prevalent research themes in blockchain-driven healthcare systems. Following this, the paper identifies major application domains and the solutions facilitated by BC in the healthcare sector.

Recent efforts to integrate BCT into several IoT scenarios and applications were evaluated in the survey papers [20-22]. The authors of [23] also discussed how BC and the IoT can work together. Smart vehicles, 5G networks, and the IoT were among the IoT applications they investigated. In addition, the technical parts of blockchain were evaluated in [24], which covered consensus methods, networking, and basic principles. The writers addressed potential benefits, drawbacks, and areas for further study in their discussion of BC and cloud computing integration [25].

Almalki J [26] examined the current state-of-the-art BC applications in different IoT disciplines, with a special focus on the healthcare sector. The aim is to highlight the promising applications of BCT in healthcare, while also discussing the obstacles and future directions in BC development. In addition, the paper offers a thorough explanation of blockchain fundamentals to appeal to a wide range of readers. Alternatively, it carefully examines the latest research in various IoT fields for eHealth, pointing out areas that need more study and challenges in combining blockchain with IoT.

BC has emerged as a highly promising and adaptable technology in the healthcare sector in recent years. According to [27], businesses that employ BCT could speed up healthcare interoperability, make medical research more focused on patients, and make it easier to spot fake medications. Furthermore, BCT can improve the precision of medical diagnoses, which is especially useful in situations when privacy and security pose major obstacles to healthcare [28]. As a result of BCT's increasing use in healthcare, doctors are starting to use innovative methods that are changing the game for the healthcare industry.

Table 1: Summary of Literature Survey on BCT in Healthcare

Reference	Methods Used	Results	Research Gap	Limitations
[82]	The survey was conducted with 50 healthcare industry respondents. Analysis of survey data for sustainability and healthcare ecosystem development.	Survey results from 50 healthcare industry respondents were analyzed. Blockchain technology enhances healthcare ecosystem sustainability and trust.	Lack of detailed exploration of blockchain implementation challenges. Limited discussion on the potential drawbacks of blockchain technology	-
[83]	Consensus algorithm and digitally distributed ledger.	BCT has significant benefits in healthcare industry applications. Improves interoperability and patient privacy.	Clinical data transaction volume Patient engagement and incentives.	Fragmented data, security, and privacy concerns.
[84]	Proposing a BC platform for sharing health data.	Proposed BC platform for sharing health data. Benefits include real-time data exchange and improved healthcare operations	Lack of evaluation on the effectiveness of the discussed benefits and limitations. Need for investments in user-friendly interfaces and user education	Fragmented health data across systems Inefficiencies due to administrative bureaucracy and data system silos
[85]	Review of BCT in healthcare systems.	Discussion of motivations and challenges in implementing BCT in healthcare	Identifying limitations of previous approaches. Open research issues and future research direction.	Limitations of earlier methods in healthcare BCT.
[86]	Assessment of BC-based healthcare technologies.	Review of BCT in healthcare and its potential applications. Identification of limitations and future research directions in this field.	Identification of limitations in previous approaches.	Open research issues and future research direction.
[87]	Incorporating BC and IoT (BCIoT) for healthcare services, developing platforms for BCIoT-driven healthcare solutions.	This survey provides a thorough examination of the integration of BC and IoT in healthcare, addressing current methodologies, challenges, and prospects	Challenges in BCIoT implementation for healthcare applications. Future directions for enhancing patient Quality of Life	Data security, single point of failure.
[88]	The development of a review process is essential and involves	Reviewed 28 research publications on BCT in dental healthcare.	Open challenges in BC-based dental care systems and	Challenges in data management,

	distinct steps during the planning, conducting, and reporting phases.	Identified challenges, proposed solutions, and discussed limitations in dental systems.	Limited adoption of BC in dentistry despite its advantages.	security, and integrity in dental care. Blockchain technology can provide solutions due to its properties.
[89]	Secure cloud storage for EHRs with data hash verification, Use of smart contracts for predefined actions in healthcare	Querying patients: 88 ms average transaction speed. Querying EHRs: 59 ms average transaction speed.	Existing healthcare problems and challenges. Objectives and limitations of related work models	-

3. Blockchain

BC functions as a decentralized and collectively managed ledger system within a peer-to-peer network [29], [30], where various users govern its operations [31]. Operating without central authority or centralized data storage administration, this method distributes data across multiple servers, ensuring data integrity through replication and encryption [32], [33]. Because of the extensive storage across numerous nodes in a distributed ledger, removing anything once it's been recorded on the blockchain poses considerable difficulty. Moreover, many blockchains utilize the advantageous feature of potential anonymity (or pseudonymity). Through the linking of each block to the preceding one via containing its hash, blockchains provide traceability and transparency. The arrangement of blocks' transactions based on Merkle trees facilitates independent verification from the root to the transaction level [34], [35].
Decentralization stands as a foundational pillar of blockchain technology. Instead of a central authority dictating content, entries into the BC are validated by the peer-to-peer network via various consensus protocols. Security of data takes centre stage in blockchain transactions, as they occur without intermediaries, virtually eliminating risks of data tampering or theft. Persistence further distinguishes blockchain, as once entries are confirmed on the shared ledger across multiple nodes [36], they become immutable. Moreover, the pseudonymous nature of blockchain finds widespread adoption across various blockchain implementations.
BC facilitates auditing and tracing by linking each new block to the preceding one, forming a chain of blocks. Transactions within blocks [37] are organized into a Merkle tree, where each leaf value is authenticated, culminating in a root value. This root value is preserved solely by the blockchain, ensuring the integrity of the tree structure. Figure 1 illustrates the architecture of BCT.

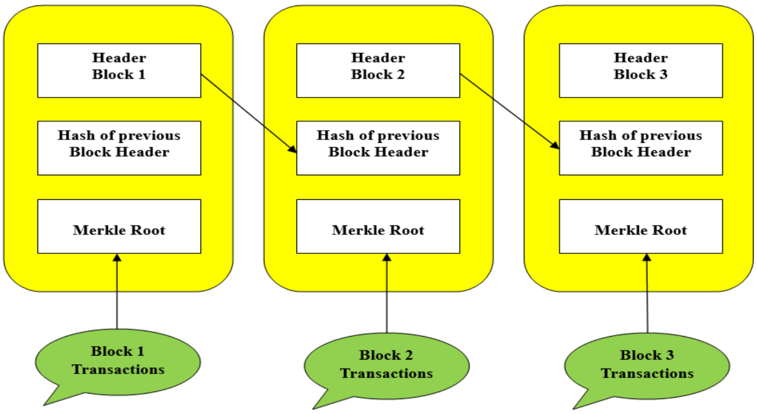

Fig. 1: Blockchain Structure.

BCT boasts several key characteristics, including transparency, distributed ledgers, data security, authentication, and decentralization. These attributes underscore the increasing popularity of this technology across various industries, particularly in sectors like healthcare, where issues concerning legitimacy, dependability, and security are particularly critical. The BC architecture, depicted in Figure 2, comprises 6 layers. Those are:
Application Layer: Users interact via blockchain applications in the application layer.
Contact Layer: The data contained within the contracts layer, situated adjacent to the application layer, outlines a service's operational procedures and the type of information that will be available, resembling the contents of a traditional real-world contract.
Incentive Layer: The third tier of this stack is the optional incentive layer, which manages the compensation provided to network nodes for their efforts in achieving consensus through rewards. Depending on the consensus mechanism, this layer may or may not be activated.

- It establishes the minimum transaction fees required for executing actions on the blockchain.
- It outlines the various types of incentives offered within the network.

Consensus Layer:

- It is essential for blockchain platforms to function. This layer is the most crucial part of any BC system, whether it's Hyperledger, Ethereum, or another one.
- The validation of blocks, their proper arrangement, and the assurance of unanimous agreement among participants are all responsibilities of the consensus layer.
- A predetermined set of agreements among nodes is established via the consensus layer within the distributed P2P network.
- The consensus layer preserves decentralised and dispersed authority.

Network Layer: P2P (peer-to-peer) and propagation layers are synonyms for the network layer, which is responsible for regulating data transfer between nodes. Node discovery, block propagation, and transactions are all handled by it. Maintaining the integrity of the BC network's present state relies on its principal function: facilitating communication, synchronisation, and propagation among nodes. In decentralised computer networks known as P2P networks, nodes located in different physical locations work together to process blockchain transactions. A "full node" and a "light node" are two different kinds of nodes. While full nodes are responsible for mining, validating transactions, and enforcing consensus rules, light nodes are limited to sending transactions and storing the Blockchain header.

Data Layer: Following the hardware layer is the data layer, responsible for storing transaction details. Each block, the fundamental unit of a blockchain, holds information such as the cryptocurrency amount sent, the recipient's public key, and the sender's private key. These blocks, which contain data, are interconnected, linking to both the preceding and subsequent blocks in the chain. However, the network's initial block, called the genesis block, is unique in that it is only connected forward, with no backward linkage.

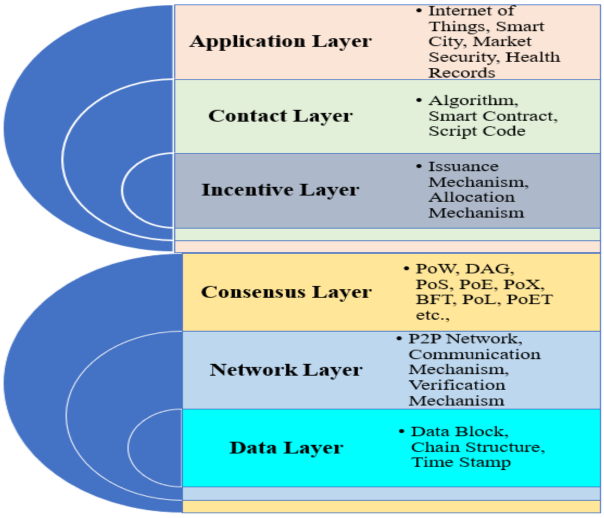

Fig. 2: Layered Architecture of Blockchain.

- Types of Blockchain

Various types of blockchains, identifying three general categories: private, public, and consortium [38]. Each type offers distinct features concerning who can write, read, and access data on the BC. In a public blockchain, the chain data is visible to everyone, allowing anyone to join, contribute, or modify the original software [38]. Public blockchains are extensively used, especially in the cryptocurrency sector. Bitcoin [39] and Ethereum [40] are two prominent examples of cryptocurrencies that utilize public BCT.
In a consortium blockchain, only specific groups have access and participation rights. In contrast, a private BC restricts access and participation solely to a centralized location, preventing external involvement [38]. The definition and classification of BC types remain ambiguous [41].

4. The role of BC in the healthcare sector

The healthcare sector is increasingly turning to BCT to tackle long-standing industry challenges. Issues such as inefficient data management and high costs associated with data coordination among industry stakeholders have posed significant challenges for organizations. As a result, numerous healthcare companies are exploring blockchain solutions as a promising avenue for overcoming these limitations within existing processes [42].
A significant barrier in the healthcare system revolves around data sharing, particularly in the transition towards value-based care, where the exchange of data among stakeholders is crucial [43]. Currently, there exist substantial silos within the system, hindering effective information exchange among groups. However, integrating the system correctly holds the promise of bridging these silos and facilitating optimal sharing and utilization of resources, thereby fostering comprehensive development [44]. Figure 3 depicts the utilization of BCT in healthcare.
BCT has potential applications in several healthcare domains to tackle important problems.

4.1. Electronic health records

Health data management, taking advantage of opportunities to link diverse systems, and improving the accuracy of EHRs are crucial if healthcare is to undergo a revolution. There is a difference between EHRs and Electronic Medical Records (EMRs), even though the two names are sometimes used interchangeably. Early medical records, or EMRs, are electronic substitutes for paper charts used by doctors and other medical professionals.
According to the mapping study, BCT facilitates the management of EHRs. In this regard, Ekblaw et al. [45] introduce MedRec, an EHR-related implementation advocating a decentralized approach to oversee authorization, permissions, and data sharing among healthcare stakeholders. MedRec leverages the Ethereum platform to empower patients with control and visibility over access to their healthcare information. Additional BC-based EMR applications, such as MedBlock [46] and Block HIE [47], offer unique functionalities. MedBlock [46] facilitates record searches by maintaining the addresses of blocks containing patient records, organized by healthcare provider or department.

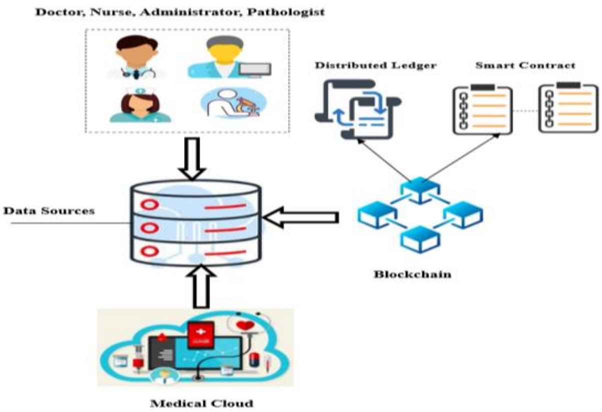

Fig. 3: Blockchain Technology in Healthcare

4.2. Third-party information management

There are many other important players in the healthcare market besides doctors, hospitals, and other medical facilities. For example, when an accident results in a patient's admission to a trauma centre, specific documents become crucial for the police. When the police update their records with facts about the injury's aetiology or similar matters, it might greatly affect the treatment plan [48].
Insurance firms also play a role in this process by managing claims and approvals. One possible way to improve data management across systems is to incorporate blockchain technology into existing data-sharing infrastructure. [49].

4.3. Remote patient monitoring

To keep tabs on a patient's condition from afar, remote patient monitoring makes use of a variety of technological tools, including mobile devices, sensors placed about the patient's body, and IoT gadgets. For the safekeeping, transfer, and retrieval of biomedical data acquired remotely, blockchain technology is necessary.
In this segment, we delve into the utilization of BCT to enhance remote patient monitoring systems. It involves the collection of biomedical data through mobile devices or body area sensors, enabling the remote monitoring of patients' conditions beyond the confines of a hospital. Blockchain serves as a valuable tool for retrieving, sharing, and securely storing the biomedical data gathered remotely [50-52]. Figure 6 depicts the utilization of IoT technologies for remote patient monitoring.
Using a scenario described by Ichikawa et al. [53], a BC-based application built on Hyperledger Fabric can receive data transmitted by mobile devices. Griggs et al. [54] demonstrate how smart contracts on Ethereum provide safe automated interventions, which in turn support applications for real-time patient monitoring. Furthermore, different strategies emphasise the enormous promise of the IoT in several fields, including e-health. To access, store, and manage electronic health records, for example, Ray et al. present IoB Health [55], a data-flow design that combines the IoT with BCT.

4.4. Health insurance claim processing

One area of healthcare that could benefit greatly from BCT is the processing of health insurance claims. This is because blockchain data is immutable, transparent, and auditable. There is a dearth of blockchain-based healthcare insurance claim processing prototypes [56] despite the clear promise of this technology. As an example, consider MIStore [57], a medical insurance system built on the blockchain that provides the insurance sector with access to encrypted and immutable data.

4.5. Health data analytics

According to [58], blockchain presents a special chance to combine with other cutting-edge technologies like DL and transfer learning methods, enabling predictive analytics of medical data and boosting precision medicine research. In the healthcare industry, [59] and [60] have also emphasised this possible use case, and [61] offers a thorough road map for leveraging blockchain in health data analytics in an intelligent manner. Furthermore, Juneja and Marefat have out exploratory studies for the classification of arrhythmias using blockchain inside a deep-learning architecture [62].

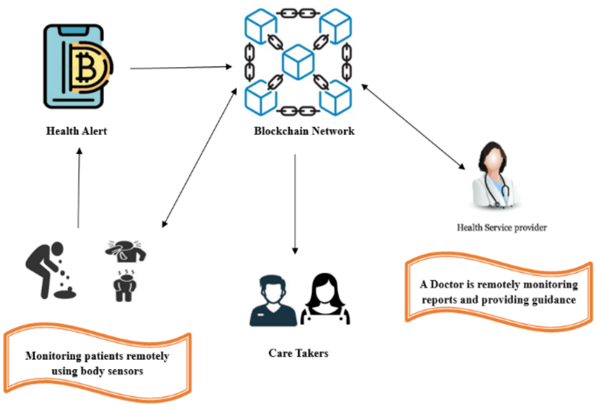

Fig. 4: Utilize IoT Technologies to Monitor Patients Remotely.

4.6. Smart contracts

Handling various contract types can result in errors, additional costs, and bureaucratic hold-ups that require time and legal resources to resolve. By authenticating the names of the organisations involved in healthcare transactions, recording the particulars of contracts, and monitoring the flow of transactions and payments for products and services, BCT has the potential to accelerate the process of streamlining interactions among stakeholders.

Extending beyond conventional supply chain management, this allows business partners and healthcare insurance providers to function using entirely digital and automated contract terms within the health sector.

Utilizing shared smart contracts among distributors and healthcare organizations on a BC ledger, as opposed to individual contract types, can notably diminish payment disputes, which tend to be protracted and resource-intensive.

4.7. Pharmaceutical supply chain

Many healthcare organisations have a vital system that is necessary for the maintenance of a robust supply chain process. Implementing a blockchain solution to successfully manage patient and inventory data within healthcare institutions might drastically minimise the amount of theft that occurs and improve the way supply chain activities are handled methodically [63].

- Supply Chain Management: BC provides a transparent and secure way to track goods through the supply chain, ensuring authenticity and reducing fraud.
- Healthcare: BC enables secure sharing of medical records between patients and healthcare providers, maintaining data privacy and integrity.
- Finance: Blockchain is used in cryptocurrencies like Bitcoin and for smart contracts, ensuring transparent and secure financial transactions.
- Voting Systems: Blockchain can be employed to create tamper-proof digital voting systems, enhancing election security and transparency.
- Intellectual Property: Blockchain helps track and verify ownership of intellectual property, ensuring rightful credit and reducing piracy.

Figure 5 flowchart depicts the process of managing healthcare data with blockchain technology, starting with system initialization and participant role setup. It includes data creation and encryption, where patient data is generated, encrypted, and signed. Blocks are then created and added to the BC via a consensus protocol[64][65], with non-consensus blocks being rejected. The flowchart also covers data access and authorization, verifying permissions and decrypting data as needed, and it details patient data updates and institution sharing, ensuring consent is obtained. Finally, auditing and compliance steps include access log reviews, data integrity checks, and alert triggers for unauthorized access, supporting secure healthcare information management[66].

5. Challenges

While acknowledging the allure of blockchain-related attributes and the potential advantages in healthcare applications, it's crucial to recognize the technology's inherent limitations. Various obstacles hinder the effective utilization of BC in healthcare. This discourse highlights some of these challenges and offers potential solutions to address them.

1) Interoperability

The challenge of interoperability arises due to the absence of a universal standard for creating BC-based healthcare. Applications developed by different vendors or on various platforms may lack interoperability. Therefore, protocols are required to ensure seamless data storage and transfer of medical records across different blockchain networks. Present efforts primarily concentrate on building prototypes and proofs-of-concept, with insufficient emphasis on achieving interoperability. Consequently, disparate BC-based healthcare platforms emerge with differing smart contract functionalities [67].

To address the interoperability challenge, a potential solution involves the development of standardized protocols ensuring compatibility among diverse blockchain products. For widespread integration of BCT into functional healthcare settings, it is imperative to establish open standards for interoperability.

2) Privacy

BC's perceived security lies in users conducting transactions with generated addresses rather than their real identities, and the ability to create multiple addresses in case of data exposure. However, studies [68] have revealed that BC fails to ensure transactional privacy as transaction values and balances associated with public keys are publicly accessible.

Blockchain enables users to conduct transactions anonymously; however, due to the public nature of transactions, identifiable clues may persist, potentially revealing users' identities and private information [69]. For instance, transactions can be linked to IP addresses, exposing user information, while third-party applications tracking users' multiple profiles and currencies, such as trading platforms, are susceptible to hacking and manipulation. To mitigate anonymity concerns in blockchains, various schemes have been suggested, such as mixing multiple input addresses to multiple output addresses and concealing the amounts and values of coins held in transactions [70], [71].

3) Scalability

Widely acknowledged challenge in BC-based healthcare solutions, largely due to the substantial volume of data they entail. Storing extensive biomedical data on the blockchain is often impractical or infeasible, as it can severely degrade performance. This scalability issue is closely tied to processing speed. Depending on the protocol employed, BC-based processing may introduce considerable latency, thereby constraining the system's scalability [67].In comparison, the Bitcoin-based Proof of Work (PoW) protocol processes approximately 288,000 transactions per day, a notably lower figure when contrasted with Visa credit cards, capable of handling up to 150 million transactions per day [72] [73].

4) Adaptability

The integrated blockchain and edge face a notable challenge due to the surge in device usage and application diversity. This challenge encompasses managing a growing user base, handling tasks of diverse complexities, and maintaining adaptability in an environment where various applications or IoT devices can freely connect to or disconnect from the BC network [74]. Acquiring and achieving high scalability in a fully decentralized and highly secure blockchain network poses significant challenges, as acknowledged by Vitalik Buterin, who deems it nearly impossible to attain such levels of scalability. Conversely, IoT devices offer greater accessibility, allowing data retrieval with ease compared to secure decentralized blockchain networks. Typically, IoT devices intermittently connect to networks at various intervals. For instance, the PBFT [75] consensus method is suitable for IoT systems; however, its applicability is limited to fixed-size networks with members who cannot readily change, making it impractical for managing a scalable number of devices.

5) Blockchain size

A sensor device links to patient data through BC transactions, including Remote Patient Monitoring (RPM) [76] and EHRs [77], which results in a continual rise in the number of miners. However, the capacity of blockchain to manage the substantial data flow from the Internet of Medical Things (IoMT) devices is limited, as indicated by several sources [78 - 80].

6) Skill-related challenges within healthcare organizations

The idea of a BCT business model remains unfamiliar to the majority. Transitioning the conventional infrastructure of RPM, EHR, Personal Health Records (PHR), and Electronic Medical Records (EMR) to BCT would entail a time-consuming process for hospitals and other healthcare organizations [81].

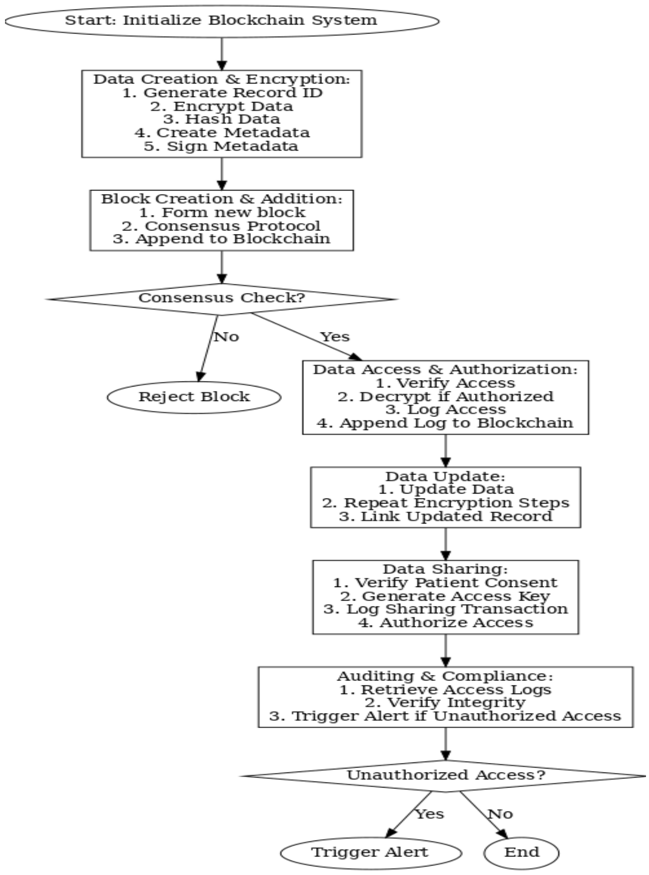

Fig. 5: Flowchart of BC Implementation in Healthcare.

6. Future advancements in BCT within the healthcare sector

In the future, BCT in healthcare is poised to undergo significant advancements and developments. Some potential areas of future work are:

- Regulatory Compliance Frameworks: Designing specialized regulatory compliance frameworks for blockchain technology (BCT) in healthcare is crucial to ensuring adherence to healthcare laws and data protection regulations. Future efforts will focus on working alongside regulatory bodies to formulate guidelines and standards for blockchain's ethical and secure application in healthcare. This will involve addressing key concerns such as data privacy, security, and legal compliance.
- Integration with Emerging Technologies: Exploring synergies between blockchain technology and other emerging technologies, such as AI, IoT, and edge computing, can unlock new possibilities for healthcare innovation. Future work involves investigating how blockchain can complement these technologies to enable advanced healthcare applications, such as personalized medicine, predictive analytics, and remote patient monitoring.
- Real-World Implementation and Adoption: Conducting real-world pilot projects and implementation studies is essential for demonstrating the feasibility and value of BCT in healthcare. Future work involves collaborating with healthcare providers, payers, and other stakeholders to pilot BC solutions in diverse healthcare settings and evaluate their impact on clinical outcomes and operational efficiency.
- Researchers should work on making sure that blockchain-based electronic health record (EHR) systems follow healthcare laws like HIPAA. They can do this by creating privacy-preserving methods like zero-knowledge proofs and safe access controls. Another significant avenue is to look at lightweight, sustainable consensus algorithms that work well in healthcare settings to solve the energy efficiency problems of blockchain. Interoperability standards, patient-centered data ownership models, and scalable architectures that can enable real-time healthcare apps should also be investigated in more studies.

By focusing on these areas of future work, BCT has the potential to revolutionize healthcare by improving data security, interoperability, transparency, and patient outcomes. However, realizing this potential requires collaboration, innovation, and ongoing efforts to address technical, regulatory, and organisational challenges.

Table 2 provides a structured overview of how AI, IoT, and ML can be integrated with BCT in healthcare, highlighting key integration aspects, benefits, and examples of use cases.

Table 2: Enhancing Healthcare with AI, IoT, and ML-Driven Blockchain Integration

Integration Aspect	Overview
Data Analytics and Insights	Integration of AI and ML with blockchain enables advanced analytics and insights generation from healthcare data stored on the BC. Example: AI analyzes patient health data collected from IoT devices and stored on the blockchain to identify patterns and personalize treatment plans.
Predictive Maintenance	AI-driven predictive maintenance models can be deployed on blockchain networks to monitor and maintain IoT devices used in healthcare settings, ensuring optimal performance and reliability. Example: Machine learning algorithms analyze historical data from IoT medical devices stored on the blockchain to predict maintenance needs and schedule proactive servicing, minimizing downtime and enhancing device longevity.
Decentralized AI Marketplaces	BC-based decentralized marketplaces enable secure and transparent trading of AI algorithms and models for healthcare applications, fostering collaboration and innovation. Example: Healthcare organizations can access and purchase AI models trained on blockchain-secured datasets through decentralized AI marketplaces, facilitating the development of AI-powered healthcare solutions while ensuring data privacy and intellectual property protection.
Data Marketplace and Monetization	Blockchain-powered data marketplaces allow healthcare organizations and individuals to securely trade and monetize IoT-generated healthcare data, while AI algorithms extract valuable insights for research and innovation. Example: Patients can opt to share their anonymized health data collected by IoT devices on a blockchain-based data marketplace, where AI-driven analytics platforms can access and analyze the data for medical research or commercial purposes, with patients receiving compensation or incentives in return.

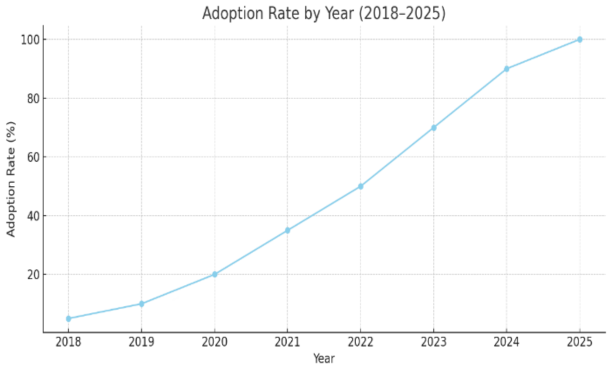

Fig. 6: Adoption Rate by Year.

Figure 6 shows how the adoption of BCT in healthcare has grown from 2018 to 2025.

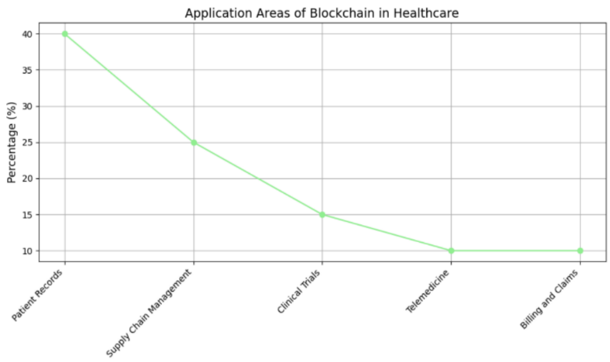

Fig. 7: Application Areas.

Highlighting the distribution of BC applications across different areas within healthcare is shown in Fig. 7.

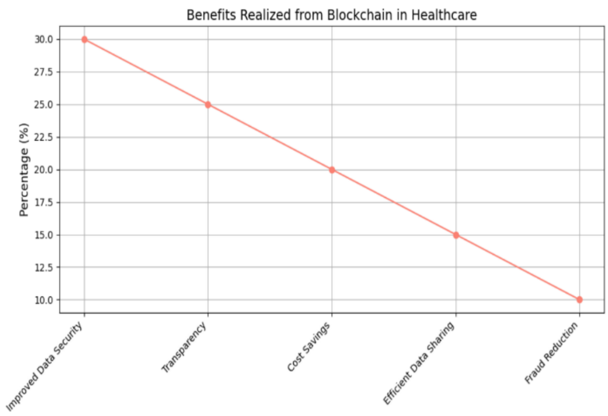

Fig. 8: Benefits Realized.

Figure 8 illustrates the key benefits that have been realized from implementing blockchain in healthcare.

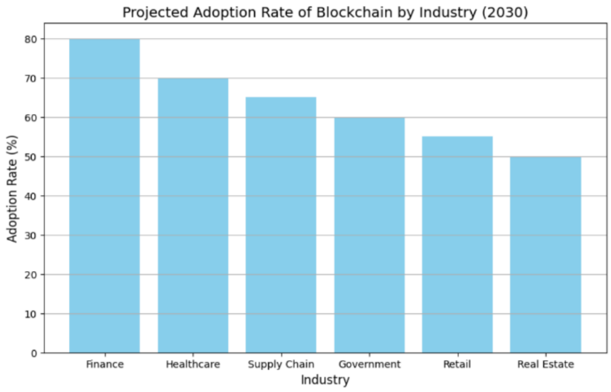

Fig. 9: Projected Adoption Rate of Blockchain by Industry.

Figure 9 bar graph illustrates the projected adoption rates of blockchain technology across various industries by the year 2030. The finance industry is expected to lead in blockchain adoption, with an 80% adoption rate. Healthcare and supply chain industries follow closely, with 70% and 65% adoption rates, respectively. Government and retail sectors are also projected to have significant adoption rates, at 60% and 55%, respectively. While lower than others, the real estate industry still shows a considerable adoption rate of 50%.

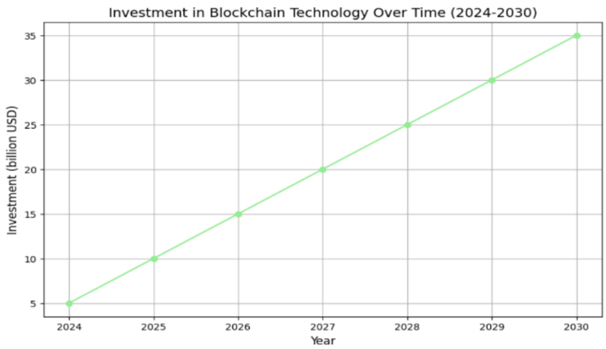

Fig. 10: Investment in Blockchain Technology Over Time (2024-2030).

Figure 10 shows the projected global investment in blockchain technology from 2024 to 2030. The investment in blockchain technology is projected to grow steadily from $5 billion in 2024 to $35 billion in 2030. The increasing trend indicates a strong confidence and interest in blockchain technology, suggesting it will continue attracting significant funding.

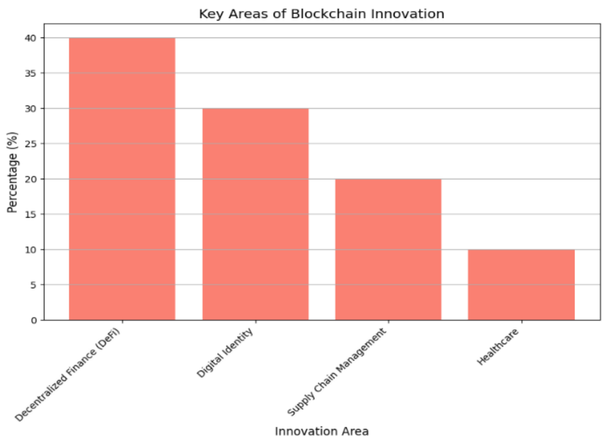

Fig. 11: Key Areas of Blockchain Innovation.

Figure 11 highlights the key areas where BCT is expected to innovate in the next decade. Decentralized Finance (DeFi) is expected to be the leading area of innovation, with 40% of efforts focused on it. Digital identity is another significant area of innovation, capturing 30%. Supply chain management and healthcare are also key areas, with 20% and 10% respectively, indicating diverse applications of BCT.

7. Threats and attacks in blockchain technology

Figure 12 categorizes the various security threats in blockchain technology into three main groups: network attacks, consensus mechanism attacks, and smart contract vulnerabilities. Each category is further subdivided into specific types of attacks that target different layers of the blockchain system.

BCT, while known for its security and transparency features, is not immune to various threats and vulnerabilities. Here are some common security threats associated with BC:

1) 51% Attack

If a single entity or group controls over 50% of a network's mining power, it can manipulate the blockchain by reversing transactions, blocking confirmations, and double-spending coins, compromising its integrity and trust.

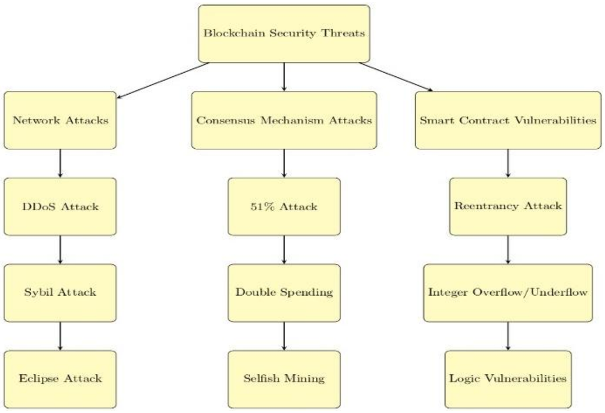

Fig. 12: Overview of Security Threats and Attacks in BCT.

2) Smart Contract Vulnerabilities
Smart contracts are self-executing contracts with the terms of the agreement directly written into code. Bugs in the code can lead to exploits. Vulnerabilities can result in financial losses, unintended contract behaviours, and exploitation by malicious actors[91].
3) Routing Attacks
These attacks involve intercepting messages in the network, potentially allowing attackers to alter or delay transactions. This can lead to transaction delays and enable double-spending attempts [90].
4) DoS Attacks
Attackers overwhelm the network with excessive requests, making it difficult for legitimate transactions to be processed. This can disrupt services and affect the usability of the blockchain network [90][91].
5) Blockchain Protocol Vulnerabilities
The underlying protocols of blockchains can have flaws that attackers can exploit, such as improper validation or inadequate consensus mechanisms. Exploiting these can lead to network failures, data corruption, and loss of funds [92].
6) Cryptojacking
Attackers use a victim's computing power to mine cryptocurrencies without their consent, often through malicious software. This can slow down the victim's system, lead to higher electricity costs, and potentially damage hardware.
7) Data Privacy Issues
While blockchain is known for transparency, sensitive data may be exposed if not properly encrypted or handled. Privacy breaches can lead to regulatory issues and loss of user trust.
To combat these threats, organizations can implement various strategies:
Regular audits and code reviews for smart contracts.
Use of multi-signature wallets for enhanced security.
Education and training programs to raise awareness about phishing and social engineering attacks.
Adoption of more robust consensus algorithms to mitigate the risk of 51% attacks.
Employing privacy-focused techniques and encryption to protect sensitive data.
Understanding and addressing these threats is crucial for maintaining the security and integrity of blockchain systems.

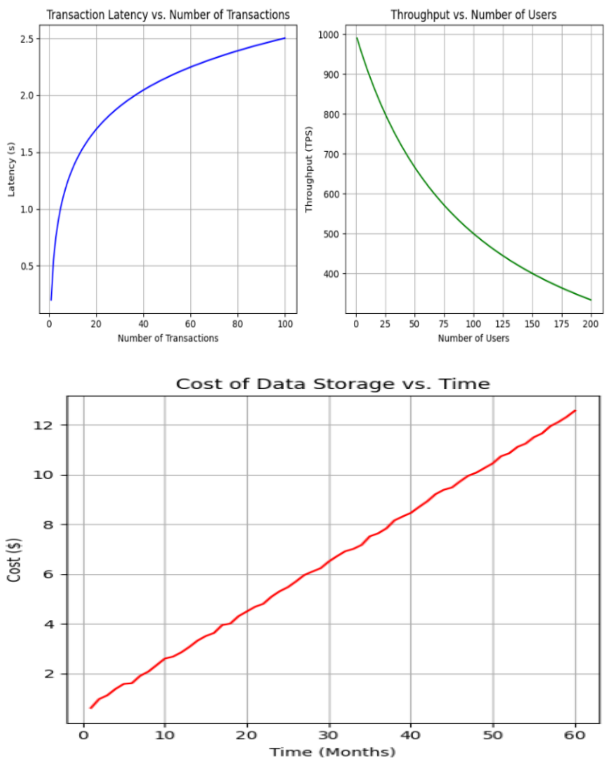

Fig. 13: Performance Evaluation of BCT.

Figure 13 shows a couple of performance graphs commonly used to compare the effectiveness of BC healthcare systems:
1) Transaction Latency vs. No.of Transactions
2) Throughput vs. No.of Users
3) Cost of Data Storage on BC vs. Time

8. Conclusion

This review paper explores the transformative role of blockchain technology (BCT) in the healthcare sector. A comprehensive analysis of existing literature and case studies reveals that blockchain offers innovative solutions to persistent challenges in global healthcare. Key features such as decentralization, immutability, and cryptographic security provide a strong foundation for maintaining the integrity and confidentiality of healthcare data. By enabling tamper-resistant records and facilitating secure, traceable transactions, blockchain enhances data interoperability and improves healthcare service delivery. Additionally, BCT supports applications like secure health information exchange, supply chain management, and clinical trial monitoring. These advancements have the potential to revolutionize healthcare by reducing costs, minimizing errors, and fostering innovation.
However, integrating BC into healthcare systems presents notable challenges. Technical hurdles, including scalability, interoperability, and regulatory compliance, must be addressed to fully realize its benefits. Additionally, concerns regarding data privacy, governance, and sustainability necessitate strategic planning and resolution. Despite these challenges, the adoption of blockchain in healthcare is accelerating. Overcoming these barriers will require collaboration among industry stakeholders, policymakers, and researchers.
In summary, while obstacles persist, the outlook for blockchain in healthcare is highly optimistic. Continued progress and investment in this technology could revolutionize healthcare systems, enhance patient outcomes, and establish a more efficient and equitable framework for the industry.

References

[1] McClean, S.; Gillespie, J.; Garg, L.; Barton, M.; Scotney, B.; Kullerton, K. Using phase-type models to cost stroke patient care across health, social and community services. Eur. J. Oper. Res. 2014, 236, 190–199. [CrossRef] https://doi.org/10.1016/j.ejor.2014.01.063.

[2] Soltanisehat, L.; Alizadeh, R.; Hao, H.; Choo, K.K.R. Technical, Temporal, and Spatial Research Challenges and Opportunities in Blockchain-Based Healthcare: A Systematic Literature Review. IEEE Trans. Eng. Manag. 2023, 70, 353–368. [CrossRef] https://doi.org/10.1109/TEM.2020.3013507.

[3] Xing, W.; Bei, Y. Medical Health Big Data Classification Based on KNN Classification Algorithm. IEEE Access 2020, 8, 28808–28819. [CrossRef] https://doi.org/10.1109/ACCESS.2019.2955754.

[4] Khan, A.A.; Wagan, A.A.; Laghari, A.A.; Gilal, A.R.; Aziz, I.A.; Talpur, B.A. BIoMT: A State-of-the-Art Consortium Serverless Network Architecture for Healthcare System Using Blockchain Smart Contracts. IEEE Access 2022, 10, 78887–78898. [CrossRef] https://doi.org/10.1109/ACCESS.2022.3194195.

[5] Quadery, S.E.U.; Hasan, M.; Khan, M.M. Consumer side economic perception of telemedicine during COVID-19 era: A survey on Bangladesh's perspective. Inform. Med. Unlocked 2021, 27, 100797. [CrossRef] [PubMed] https://doi.org/10.1016/j.imu.2021.100797.

[6] M.H. Kassab, J. DeFranco, T. Malas, Giuseppe Destefanis Laplante, V.V. Neto, Exploring research in Blockchain for healthcare and a roadmap for the future, IEEE Trans. Emerg. Top. Comput. (2019), 1-1.

[7] B. Shen, J. Guo, Y. Yang, MedChain: efficient healthcare data sharing via Blockchain, Appl. Sci. 9 (6) (2019) 1207 https://doi.org/10.3390/app9061207.

[8] O'donoghue O., Vazirani A. A., Brindley D., & Meinert E. (2019). Design choices and trade-offs in health care blockchain implementations: systematic review. Journal of medical Internet research, 21 (5), e12426. https://doi.org/10.2196/12426.

[9] Ozdagoglu G., Damar M., & Ozdagoglu A. (2020). The State of the art in blockchain research (2013– 2018): scientometrics of the related papers in web of science and scopus. In Digital Business Strategies in Blockchain Ecosystems (pp. 569–599). Springer, Cham. https://doi.org/10.1007/978-3-030-29739-8_27.

[10] Kitchenham B., Brereton O. P., Budgen D., Turner M., Bailey J., & Linkman S. (2009). Systematic literature reviews in software engineering–a systematic literature review. Information and software technology, 51(1), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009.

[11] Gopalakrishnan S., & Ganeshkumar P. (2013). Systematic reviews and meta-analysis: understanding the best evidence in primary healthcare. Journal of family medicine and primary care, 2(1), 9. https://doi.org/10.4103/2249-4863.109934.

[12] Abou Jaoude J., & Saade R. G. (2019). Blockchain applications–usage in different domains. IEEE Access, 7, 45360–45381. https://doi.org/10.1109/ACCESS.2019.2902501.

[13] Ho¨lbl M., Kompara M., Kamisˇalić A., & Nemec Zlatolas L. (2018). A systematic review of the use of blockchain in healthcare. Symmetry, 10(10), 470. https://doi.org/10.3390/sym10100470.

[14] Mendling J., Weber I., Aalst W. V. D., Brocke J. V., Cabanillas C., Daniel F., et al. (2018). Blockchains for business process management-challenges and opportunities. ACM Transactions on Management Information Systems (TMIS), 9(1), 1–16. https://doi.org/10.1145/3183367.

[15] Kuo T. T., Gabriel R. A., & Ohno-Machado L. (2019). Fair compute loads enabled by blockchain: sharing models by alternating client and server roles. Journal of the American Medical Informatics Association, 26(5), 392–403. https://doi.org/10.1093/jamia/ocy180.

[16] Meinert E., Alturkistani A., Foley K., Osama T., Car J., Majeed F., et al. Implementation of blockchains in healthcare: protocol for a systematic review.

[17] Hussien, H. M., Yasin, S. M., Udzir, N. I., Ninggal, M. I. H., & Salman, S. (2021). Blockchain technology in the healthcare industry: Trends and opportunities. *Journal of Industrial Information Integration*, *22*, 100217. https://doi.org/10.1016/j.jii.2021.100217.

[18] Underwood, Sarah. "Blockchain beyond bitcoin." Communications of the ACM 59, no. 11 (2016): 15-17. https://doi.org/10.1145/2994581.

[19] Ghosh, P. K., Chakraborty, A., Hasan, M., Rashid, K., & Siddique, A. H. (2023). Blockchain application in healthcare systems: A review. *Systems*, *11*(1), 38. https://doi.org/10.3390/systems11010038.

[20] Ferrag, M.A.; Derdour, M.; Mukherjee, M.; Derhab, A.; Maglaras, L.; Janicke, H.: Blockchain technologies for the internet of things: research issues and challenges. IEEE Internet Things J. 6(2), 2188–2204 (2019). https://doi.org/10.1109/JIOT.2018.2882794.

[21] Ali, M.S.; Vecchio, M.; Pincheira, M.; Dolui, K.; Antonelli, F.; Rehmani, M.H.: Applications of blockchains in the internet of things: A comprehensive survey. IEEE Commun. Surv. Tutor. 21(2), 1676–1717 (2019). https://doi.org/10.1109/COMST.2018.2886932.

[22] Fernández-Caramés, T.M.; Fraga-Lamas, P.: A review on the use of blockchain for the internet of things. IEEE Access 6, 32979– 33001 (2018). https://doi.org/10.1109/ACCESS.2018.2842685.

[23] Dai, H.-N.; Zheng, Z.; Zhang, Y.: Blockchain for internet of things: a survey. IEEE Internet Things J. 6(5), 8076–8094 (2019). https://doi.org/10.1109/JIOT.2019.2920987.

[24] Mingli,W.;Wang, K.; Cai, X.; Guo, S.; Guo, M.; Rong, C.: A comprehensive survey of blockchain: From theory to IoT applications and beyond. IEEE Internet Things J. 6(5), 8114–8154 (2019). https://doi.org/10.1109/JIOT.2019.2922538.

[25] Park, J.H.; Park, J.H.: Blockchain security in cloud computing: use cases, challenges, and solutions. Symmetry 9(8), 164 (2017) https://doi.org/10.3390/sym9080164.

[26] Almalki, J. (2024). State-of-the-art research in blockchain of things for healthcare. *Arabian Journal for Science and Engineering*, *49*(3), 3163-3191. https://doi.org/10.1007/s13369-023-07896-5.
[27] Wang S, Wang J, Wang X, Qiu T, Yuan Y, Ouyang L, Guo Y, Wang F-Y (2018) Blockchain-powered parallel healthcare systems based on the ACP approach. IEEE Trans Comput Soc Syst 5:942–950. https://doi.org/10.1109/TCSS.2018.2865526.
[28] 28. Zhang A, Lin X (2018) Towards Secure and Privacy-Preserving Data Sharing in e-Health Systems via Consortium Blockchain. J. Med. Syst. 42. https://doi.org/10.1007/s10916-018-0995-5.
[29] Rabah, K.: Challenges and opportunities for blockchain powered healthcare systems: a review. Mara. Res. J. Med. Health Sci. 1(1), 45–52 (2017).
[30] Hölbl, M.; Kompara, M.; Kamišali´c, A.; Nemec Zlatolas, L.: A systematic review of the use of blockchain in healthcare. Symmetry 10(10), 470 (2018). https://doi.org/10.3390/sym10100470.
[31] McGhin, T.; Raymond Choo, K.-K.; Zhechao Liu, C.; He, D.: Blockchain in healthcare applications: research challenges and opportunities. J. Netw. Comput. Appl. 135, 62–75 (2019). https://doi.org/10.1016/j.jnca.2019.02.027.
[32] Esposito, C.; De Santis, A.; Tortora, G.; Chang, H.; Choo, K.-K.R.: Blockchain: A panacea for healthcare cloud-based data security and privacy? IEEE Cloud Comput. 5(1), 31–37 (2018). https://doi.org/10.1109/MCC.2018.011791712.
[33] Engelhardt,M.A: Hitching healthcare to the chain: an introduction to blockchain technology in the healthcare sector. Technol. Innov. Manag. Rev., 7(10) (2017). https://doi.org/10.22215/timreview/1111.
[34] Zheng Z, Xie S, Dai H, Chen X, Wang H. An overview of blockchain technology: architecture, consensus, and future trends. In: 2017 IEEE International Congress on Big Data (BigData Congress). Honolulu, HI: IEEE (2017), p. 557–64. https://doi.org/10.1109/BigDataCongress.2017.85.
[35] Merkle RC. One way hash functions and DES. In: Brassard G, editor. Advances in Cryptology—CRYPTO'89 Proceedings. New York, NY: Springer (2001), p. 428–46. doi: 10.1007/0-387-34805-0_40. https://doi.org/10.1007/0-387-34805-0_40.
[36] Chinaei, M.H.; Gharakheili, H.H.; Sivaraman, V. Optimal Witnessing of Healthcare IoT Data Using Blockchain Logging Contract. IEEE Internet Things J. 2021, 8, 10117–10130. [CrossRef]. https://doi.org/10.1109/JIOT.2021.3051433.
[37] Egala, B.S.; Pradhan, A.K.; Badarla, V.; Mohanty, S.P. Fortified-Chain: A Blockchain-Based Framework for Security and Privacy Assured Internet of Medical Things With Effective Access Control. IEEE Internet Things J. 2021, 8, 11717–11731. [CrossRef]. https://doi.org/10.1109/JIOT.2021.3058946.
[38] Chinaei, M.H.; Gharakheili, H.H.; Sivaraman, V. Optimal Witnessing of Healthcare IoT Data Using Blockchain Logging Contract. IEEE Internet Things J. 2021, 8, 10117–10130. [CrossRef]. https://doi.org/10.1109/JIOT.2021.3051433.
[39] Li, P.; Xu, C.; Jin, H.; Hu, C.; Luo, Y.; Cao, Y.; Mathew, J.; Ma, Y. ChainSDI: A Software-Defined Infrastructure for Regulation Compliant Home-Based Healthcare Services Secured by Blockchains. IEEE Syst. J. 2020, 14, 2042–2053. [CrossRef]. https://doi.org/10.1109/JSYST.2019.2937930.
[40] Qahtan, S.; Sharif, K.Y.; Zaidan, A.A.; Alsattar, H.A.; Albahri, O.S.; Zaidan, B.B.; Zulzalil, H.; Osman, M.H.; Alamoodi, A.H.; Mohammed, R.T. Novel Multi Security and Privacy Benchmarking Framework for Blockchain-Based IoT Healthcare Industry 4.0 Systems. IEEE Trans. Ind. Inform. 2022, 18, 6415–6423. [CrossRef] https://doi.org/10.1109/TII.2022.3143619.
[41] Kapadiya, K.; Patel, U.; Gupta, R.; Alshehri, M.D.; Tanwar, S.; Sharma, G.; Bokoro, P.N. Blockchain and AI-Empowered Healthcare Insurance Fraud Detection: An Analysis, Architecture, and Future Prospects. IEEE Access 2022, 10, 79606–79627. [CrossRef]. https://doi.org/10.1109/ACCESS.2022.3194569.
[42] Wang, Huaiqing, Kun Chen, and Dongming Xu. "A maturity model for blockchain adoption." Financial Innovation 2, no. 1 (2016): 12. https://doi.org/10.1186/s40854-016-0031-z.
[43] Yadav, Vinay Surendra, and A. R. Singh. "A Systematic Literature Review of Blockchain Technology in Agriculture." 2017.
[44] XXu, Z., J. Kim, S. Ryu, D. Alevtina, and F. Wang. "secure Electronic Medical Records Sharing Using Block chain: su-i-gpd-j-100." Medical Physics 44, no. 6 (2017): 2822.
[45] Ekblaw, A., Azaria, A., Halamka, J.D., Lippman, A.: A case study for blockchain in healthcare: "MedRec" prototype for electronic health records and medical research data. In: Proceedings of IEEE Open & Big Data Conference, vol. 13, p. 13 (2016).
[46] Fan, K., Wang, S., Ren, Y., Li, H., Yang, Y.: Medblock: efficient and secure medical data sharing via blockchain. J. Med. Syst. 42(8), 136 (2018). https://doi.org/10.1007/s10916-018-0993-7.
[47] Jiang, S., Cao, J., Wu, H., Yang, Y., Ma, M., He, J.: BlocHIE: a blockchain-based platform for healthcare information exchange. In: IEEE International Conference on Smart Computing (SMARTCOMP), pp. 49–56. IEEE (2018). https://doi.org/10.1109/SMARTCOMP.2018.00073.
[48] XXu, Z., J. Kim, S. Ryu, D. Alevtina, and F. Wang. "secure Electronic Medical Records Sharing Using Block chain: su-i-gpd-j-100." Medical Physics 44, no. 6 (2017): 2822.
[49] Siyal, Asad, Aisha Junejo, Muhammad Zawish, Kainat Ahmed, Aiman Khalil, and Georgia Soursou. "Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives." Cryptography 3, no. 1 (2019): 3. https://doi.org/10.3390/cryptography3010003.
[50] Sharma, A.; Kaur, S.; Singh, M. A comprehensive review on blockchain and Internet of Things in healthcare. Trans. Emerg. Telecommun. Technol. 2021, 32, e4333. [CrossRef]. https://doi.org/10.1002/ett.4333.
[51] Zhang, J.; Xue, N.; Huang, X. A Secure System For Pervasive Social Network-Based Healthcare. IEEE Access 2016, 4, 9239–9250. [CrossRef]. https://doi.org/10.1109/ACCESS.2016.2645904.
[52] Weiss, M.; Botha, A.; Herselman, M.; Loots, G. Blockchain as an enabler for public mHealth solutions in South Africa. In Proceedings of the 2017 IST-Africa Week Conference, Windhoek, Namibia, 31 May–2 June 2017; pp. 1–8. [CrossRef]. https://doi.org/10.23919/ISTAFRICA.2017.8102404.
[53] Ichikawa, D., Kashiyama, M., Ueno, T.: Tamper-resistant mobile health using blockchain technology. JMIR mHealth uHealth 5(7), e111 (2017). https://doi.org/10.2196/mhealth.7938.
[54] Griggs, K.N., Ossipova, O., Kohlios, C.P., Baccarini, A.N., Howson, E.A., Hayajneh, T.: Healthcare blockchain system using smart contracts for secure automated remote patient monitoring. J. Med. Syst. 42(7), 130 (2018). https://doi.org/10.1007/s10916-018-0982-x.
[55] Ray, P.P., Dash, D., Salah, K., Kumar, N.: Blockchain for IoT-based healthcare: background, consensus, platforms, and use cases. IEEE Syst. J. (2020). https://doi.org/10.1109/JSYST.2020.2963840.
[56] Gatteschi, V., Lamberti, F., Claudio, D., V´ıctor, S.: Blockchain and smart contracts for insurance: Is the technology mature enough?, February 2018. https://doi.org/10.3390/fi10020020.
[57] Zhou, L., Wang, L., Sun, Y.: MIStore: a blockchain-based medical insurance storage system. J. Med. Syst. 42(8), 149 (2018). https://doi.org/10.1007/s10916-018-0996-4.
[58] Shae, Z., & Tsai,J. (2018). Transform Blockchain into Distributed Parallel Computing Architecture for Precision Medicine. In Proceedings of the IEEE 38th International Conference on Distributed Computing Systems (pp. 1290–1299). IEEE. https://doi.org/10.1109/ICDCS.2018.00129.
[59] Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: Promises, challenges, and scenariosin health and healthcare. International Journal of Health Geographics, 17(1), 25. https://doi.org/10.1186/s12942-018-0144-x.
[60] Roman-Belmonte, J. M., De la Corte-Rodriguez, H., Rodriguez-Merchan, E. C. C., la Corte-Rodriguez, H., & Carlos Rodriguez-Merchan, E. (2018). How blockchain technology can change medicine. Postgraduate Medicine, 130(4), 420–427. https://doi.org/10.1080/00325481.2018.1472996.
[61] Mamoshina, P., Ojomoko, L., Yanovich, Y., Ostrovski, A., Botezatu, A., Prikhodko, P., & Zhavoronkov, A. et al. (2017). Converging blockchain and next-generation artificial intelligence technologies to decentralize and accelerate biomedical research and healthcare. Oncotarget, 9(5), 5665–5690. https://doi.org/10.18632/oncotarget.22345.
[62] Marefat, M., & Juneja, A. (2018). Leveraging Blockchain for Retraining Deep learnign Architecture in PatientSpecific Arrhythmia Classification. In Proceedings of the 2018 IEEE EMBS International Conference on Biomedical & Health Informatics (BHI) (pp. 393–397). IEEE. https://doi.org/10.1109/BHI.2018.8333451.
[63] Mangesius, Patrick, Johannes Bachmann, Thomas Healy, SamrendSaboor, and Thomas Schabetsberger. "Blockchains in IHE-Based Networks." Studies in health technology and informatics 251 (2018): 27-30. https://doi.org/10.3233/978-1-61499-880-8-27.

[64] Khezr, S.; Moniruzzaman, M.; Yassine, A.; Benlamri, R. Blockchain Technology in Healthcare: A Comprehensive Review and Directions for Future Research. *Appl. Sci.* 2019, *9*, 1736. https://doi.org/10.3390/app9091736.

[65] Hölbl M, Kompara M, Kamišalić A, Nemec Zlatolas L. A Systematic Review of the Use of Blockchain in Healthcare. *Symmetry*. 2018; 10(10):470. https://doi.org/10.3390/sym10100470.

[66] Ahmed Teli, Tawseef and Masoodi, Faheem, Blockchain in Healthcare: Challenges and Opportunities (July 8, 2021). Proceedings of the International Conference on IoT Based Control Networks & Intelligent Systems - ICICNIS 2021, https://ssrn.com/abstract=3882744. https://doi.org/10.2139/ssrn.3882744.

[67] Agbo, C. C., & Mahmoud, Q. H. (2020). Blockchain in healthcare: Opportunities, challenges, and possible solutions. *International Journal of Healthcare Information Systems and Informatics (IJHISI)*, *15*(3), 82-97. https://doi.org/10.4018/IJHISI.2020070105.

[68] Kosba, A., Miller, A., Shi, E., Wen, Z., Papamanthou, C.: Hawk: The blockchain model of cryptography and privacy-preserving smart contracts. In: Proceedings of IEEE Symposium on Security and Privacy (SP). pp. 839–858. San Jose, CA, USA (2016). https://doi.org/10.1109/SP.2016.55.

[69] Alex Biryukov, Dmitry Khovratovich, and Ivan Pustogarov. Deanonymisation of clients in bitcoin P2P network. In Proceedings of the 2014 ACM SIGSAC Conference on Computer and Communications Security, CCS '14, pages 15–29, New York, NY, USA, 2014. ACM. https://doi.org/10.1145/2660267.2660379.

[70] Jan Camenisch, Manu Drijvers, and Maria Dubovitskaya. Practical ucsecure delegatable credentials with attributes and their application to blockchain. In Proceedings of the 2017 ACM SIGSAC Conference on Computer and Communications Security, CCS '17, pages 683–699, New York, NY, USA, 2017. ACM. https://doi.org/10.1145/3133956.3134025.

[71] Zibin Zheng, Shaoan Xie, Hong-Ning Dai, Xiangping Chen, and Huaimin Wang. Blockchain challenges and opportunities: A survey. 12 2017.

[72] Kuo, T. T., Kim, H. E., & Ohno-Machado, L. (2017). Blockchain distributed ledger technologies for biomedical and health care applications. Journal of the American Medical Informatics Association, 24(6), 1211–1220. https://doi.org/10.1093/jamia/ocx068.

[73] Esposito, C., De Santis, A., Tortora, G., Chang, H., & Choo, K. R. (2018). Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy? IEEE Cloud Computing, 5(1), 31–37. https://doi.org/10.1109/MCC.2018.011791712.

[74] Almalki, J. (2023). State-of-the-Art Research in Blockchain of Things for HealthCare. *Arabian Journal for Science and Engineering*, 1-29.

[75] Castro, M.; Liskov, B.; et al.: Practical byzantine fault tolerance. OsDI 99, 173–186 (1999)

[76] K.N. Griggs, O. Ossipova, C.P. Kohlios, A.N. Baccarini, E.A. Howson, T. Hayajneh, Healthcare blockchain system using smart contracts for secure automated remote patient monitoring, J. Med. Syst. 42 (7) (2018) 130. https://doi.org/10.1007/s10916-018-0982-x.

[77] S. Badr, I. Gomaa, E. Abd-Elrahman, Multi-tier blockchain framework for IoTEHRs systems, Procedia Comput. Sci. 141 (2018) 159-166. https://doi.org/10.1016/j.procs.2018.10.162.

[78] W. Viriyasitavat, T. Anuphaptrirong, D. Hoonsopon, When blockchain meets internet of things: characteristics, challenges, and business opportunities, J. Indus. Inf. Integr. 15 (2019) 21–28. https://doi.org/10.1016/j.jii.2019.05.002.

[79] W. Viriyasitavat, L. Da Xu, Z. Bi, A. Sapsomboon, New blockchain-based architecture for service interoperations in internet of things, IEEE Trans. Comput. Soc. Syst. 6 (4) (2019) 739–748. https://doi.org/10.1109/TCSS.2019.2924442.

[80] W. Viriyasitavat, L. Da Xu, Z. Bi, D. Hoonsopon, N. Charoenruk, Managing qos of internet-of-things services using blockchain, IEEE Trans. Comput. Soc. Syst. 6 (6) (2019) 1357–1368. https://doi.org/10.1109/TCSS.2019.2919667.

[81] S.G. Alonso, J. Arambarri, M. Lopez-Coronado, ´ I. de la Torre Díez, Proposing new blockchain challenges in ehealth, J. Med Syst 43 (3) (2019) 64. https://doi.org/10.1007/s10916-019-1195-7.

[82] Sofiene, Mansouri., Souhir, Chabchoub., Yousef, Alharbi., Abdulrahman, Alqahtani. (2023). Blockchain Technology in Enhancing Health Care Ecosystem for Sustainable Development. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, https://doi.org/10.58346/JOWUA.2023.I3.018.

[83] Yuvraj, Singh., M., A., Jabbar., Shishir, Kumar, Shandilya., Olena, Vovk., Yaroslav, Hnatiuk. (2023). Exploring applications of blockchain in healthcare: road map and future directions. Frontiers in Public Health, https://doi.org/10.3389/fpubh.2023.1229386.

[84] Stefano, Abbate., Piera, Centobelli., Roberto, Cerchione., Eugenio, Oropallo., Emanuela, Riccio. (2023). Blockchain Technology for Embracing Healthcare 4.0. IEEE Transactions on Engineering Management, https://doi.org/10.1109/TEM.2022.3212007.

[85] Sadia, Ramzan., Aqsa, Aqdus., Vinayakumar, Ravi., Deepika, Koundal., Rashid, Amin., Mohammed, A., Al, Ghamdi. (2023). Healthcare Applications Using Blockchain Technology: Motivations and Challenges. IEEE Transactions on Engineering Management, https://doi.org/10.1109/TEM.2022.3189734.

[86] (2023). Healthcare Applications Using Blockchain Technology: Motivations and Challenges. IEEE Transactions on Engineering Management, https://doi.org/10.1109/TEM.2022.3189734.

[87] Αρετή, Σακελλαρίδου. (2023). Amalgamation of Blockchain with resource-constrained IoT devices for healthcare applications – State of art, challenges and future directions. International journal of cognitive computing in engineering, https://doi.org/10.1016/j.ijcce.2023.06.002.

[88] T., Mokhamed., Manar, Abu, Talib., Mohammad, Adel, Moufti., Sohail, Abbas., Faheem, Khan. (2023). The Potential of Blockchain Technology in Dental Healthcare: A Literature Review. Sensors, https://doi.org/10.3390/s23063277.

[89] Ashraf, Mohey, Eldin., Eman, Hossny., Khaled, T., Wassif., Fatma, A., Omara. (2023). Federated blockchain system (FBS) for the healthcare industry. Dental science reports, https://doi.org/10.1038/s41598-023-29813-4.

[90] Jan Heinrich Beinke, Christian Fitte, Frank Teuteberg, Towards a stakeholder or iented blockchain-based architecture for electronic health records: design science research study.", J. Med. Internet Res. 21.10 (2019) e13585. https://doi.org/10.2196/13585.

[91] Khaled Shuaib, et al., Blockchains for secure digitized medicine.", J. Pers. Med. 9.3 (2019) 35. https://doi.org/10.3390/jpm9030035.

[92] Abu-Elezz, I., Hassan, A., Nazeemudeen, A., Househ, M., & Abd-Alrazaq, A. (2020). The benefits and threats of blockchain technology in healthcare: A scoping review. *International Journal of Medical Informatics*, *142*, 104246. https://doi.org/10.1016/j.ijmedinf.2020.104246.