Blockchain-driven Transformation in Healthcare 5.0: Opportunities and Challenges

Omkar Singh*
National Institute of Fashion Technology, Patna, Bihar, India.

Navanendra Singh
National Institute of Fashion Technology, Patna, Bihar, India.

Vinoth R
National Institute of Fashion Technology, Patna, Bihar, India.

Abhilasha Singh
National Institute of Fashion Technology, Patna, Bihar, India.

ABSTRACT

With the advent of Healthcare 5.0, medical systems are entering a revolutionary era marked by connected, intelligent, and personalised services driven by cutting-edge technologies. Blockchain stands out among these as a key component that makes decentralised, transparent, and safe data management possible. The disruptive influence of blockchain in Healthcare 5.0 is examined in this article, along with the major opportunities it presents and the technical, moral, and legal issues that need to be resolved. We explore how blockchain facilitates new use cases like smart contracts and decentralised clinical trials, improves data integrity, safeguards patient-centric information, and promotes interoperability. Future directions and strategic frameworks for successful implementation are included in the paper's conclusion.

Keywords: Blockchain, Healthcare 5.0, Smart Contracts, Interoperability, Data Security, Decentralized Clinical Trials, Patient-Centric Care

1 Introduction

New technologies that promise more intelligent, individualised, and effective medical care are causing a significant shift in the worldwide healthcare system [1]. In order to establish a human-centric, predictive, and preventative health ecosystem, this evolution—often referred to as Healthcare 5.0 integrates intelligent digital tools—such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and big data—into patient care. In the midst of this digital explosion, blockchain technology has become a disruptive force that can solve persistent problems with healthcare systems' data security, transparency, interoperability, and trust [2]. Blockchain makes it possible for safe and instantaneous access to electronic health records (EHRs), transparent clinical trials, and improved drug traceability across supply chains by providing decentralised data storage, immutable records, and cryptographic verification. Additionally, it gives individuals authority over their medical records and facilitates automation via smart contracts, allowing for smooth compliance management and healthcare operations [3]. Notwithstanding these encouraging qualities, there are a number of obstacles to overcome when incorporating blockchain technology into the intricate and strictly regulated healthcare industry, such as scalability issues, legacy system interoperability issues, ethical dilemmas, and regulatory uncertainty [4]. It takes a systematic and cooperative strategy involving technology developers, healthcare providers, policy makers, and patients to go from idea acceptance to realistic, scalable implementation. The implementation of blockchain in Healthcare 5.0 presents both potential and problems, which are examined in this research paper [5]. It analyses organisational, ethical, and technical barriers while providing a thorough overview of how blockchain might propel change across a range of healthcare services. Along with providing real-world case studies to illustrate impact, the paper also gives a strategic implementation strategy to help guide successful integration [6]. This study intends to advance knowledge of how blockchain can be a fundamental technology in influencing the direction of healthcare by identifying important drivers, barriers, and feasible routes [7].

Doi:10.48047/ijiee.2025.15.6.25

Fig. 1: Blockchain-driven transformation in Healthcare 5.0

1.1. Overview of Healthcare Evolution

From basic services to complex, technologically empowered ecosystems, healthcare has changed over time. After Healthcare 1.0, which was characterised by reactive care and dispersed services, later stages brought structured public health (2.0), EMRs and digitisation (3.0), and data-driven integration using IoT, AI, and big data (4.0). The next step is healthcare 5.0, which emphasises autonomous, predictive, and human-centered care models backed by real-time analytics and cutting-edge technologies [8].

1.2. Concept of Healthcare 5.0

The future-focused approach known as Healthcare 5.0 is propelled by cognitive computing, cyber-physical systems, and hyper-connectivity. It promotes prevention, proactive health management, and personalisation by fusing Industry 5.0 concepts with healthcare requirements [9]. It seeks to provide patient-centered, value-based care while cutting expenses, minimising inefficiencies, and enhancing patient outcomes. The foundation of this change is the integration of AI, IoT, robotics, and immersive technologies [10].

1.3. Role of Emerging Technologies

Healthcare 5.0 integrates an ecosystem of technologies:

- **Artificial Intelligence (AI):** Enabling predictive analytics, diagnostics, and automation [11].
- **Internet of Things (IoT):** Facilitating remote monitoring and real-time data collection [12].
- **5G Connectivity:** Enabling ultra-fast, low-latency communications [13].
- **Cloud Computing:** Providing scalable, flexible data storage and sharing [14].
- **Augmented and Virtual Reality (AR/VR):** Enhancing surgical planning, medical training, and patient engagement [15].
- **Blockchain:** Introducing immutable, decentralized, and secure information management systems [16].

1.4. Blockchain as a Disruptive Technology in Healthcare

Blockchain brings about a fundamental change in the way that medical data is protected, accessed, and maintained. In a setting where data privacy, integrity, and accessibility are crucial, its fundamental qualities—decentralization, immutability, transparency, and security—are essential [17]. Blockchain makes it possible for:

- Secure sharing of patient health records.
- Real-time access and traceability in drug supply chains.
- Automated, verifiable claims processing.
- Decentralized clinical trials with tamper-proof data.
- Enhanced consent management and patient identity control. As healthcare systems increasingly adopt data-intensive and collaborative approaches, blockchain emerges as a key enabler of trust and efficiency across the value chain [18].

2 Blockchain Technologies: Fundamentals

Blockchain is a decentralised digital ledger technology that transparently and irrevocably records transactions via a dispersed network of computers [19]. Without the need for a central authority, it functions via a consensus process that guarantees that all participants concur on the legitimacy of transactions. The chain is impenetrable because every block includes a cryptographic hash of the one before it. Blockchain-coded self-executing agreements known as "smart contracts" automate procedures and enforce regulations. Decentralisation, transparency, security, and trust are the fundamental tenets of blockchain, which make it a viable option for safe data management in the medical field and other fields [20].

2.1. Core Principles

Doi:10.48047/ijiee.2025.15.6.25

Blockchain is a distributed ledger technology (DLT) that uses a decentralised network to securely, verifiably, and irrevocably record transactions [21]. Among its guiding concepts are:

- **Decentralization:** Eliminates the need for a central authority, reducing the risk of single points of failure [22].
- **Transparency:** All participants can access and audit the same immutable records [23].
- **Immutability:** Once data is recorded, it cannot be altered retroactively [24].
- **Security:** Cryptographic algorithms secure data, ensuring authenticity and integrity [25].
- **Consensus Mechanisms:** Ensure agreement among distributed nodes for transaction validation (e.g., Proof of Work, Proof of Stake, Byzantine Fault Tolerance) [26].

2.2. Blockchain Architecture

Blockchain architecture is typically composed of the following layers:

- **Data Layer:** Stores blocks of information containing transaction data [27].
- **Network Layer:** Facilitates peer-to-peer communication and data propagation [28].
- **Consensus Layer:** Implements protocols to validate and agree on the current state [29].
- **Application Layer:** Interfaces with decentralized applications (dApps) and smart contracts. Each block includes a hash of the previous block, a timestamp, and transaction data, forming an unbreakable chain of records [30].

2.3. Types of Blockchains

- **Public Blockchain:** Open to anyone to join and participate (e.g., Bitcoin, Ethereum). Offers high transparency but can be resource-intensive [31].
- **Private Blockchain:** Access is restricted to specific participants, often used in enterprises and healthcare consortia [32].
- **Consortium Blockchain:** Controlled by a group of institutions, balancing decentralization with controlled participation—ideal for healthcare ecosystems. Each type serves different use cases depending on security, performance, and governance needs [33].

2.4. Smart Contracts and Decentralized Applications

Blockchain-coded self-executing agreements are known as smart contracts. They minimise administrative overhead and human interaction by automatically executing actions when predetermined circumstances are met [34]. Smart contracts in healthcare enable:Automated insurance claim processing

- Consent management
- Drug traceability
- Clinical trial participation and incentives

These features are further expanded by blockchain-based decentralised applications (dApps), which provide safe and expandable platforms for the provision of healthcare services [35].

Table 1: Blockchain Technologies Fundamentals

Concept	Description	Example in Healthcare
Distributed Ledger [36]	A decentralized database shared across a network of nodes.	All hospitals have a synchronized copy of patient treatment data.
Cryptographic Security [37]	Ensures data integrity and privacy using encryption techniques.	Encrypted patient records are only accessible by authorized users.
Consensus Mechanisms [38]	Protocols like PoW, PoS, and PBFT ensure agreement across distributed systems.	Proof of Authority (PoA) for validating hospital transactions
Smart Contracts [39]	Self-executing code that automates agreements and processes.	Automatically release insurance after treatment confirmation.
Immutability [40]	Once recorded, data cannot be altered or deleted.	Tamper-proof audit trail of clinical trials.
Transparency & Trust [41]	All transactions are visible and verifiable by participants.	Patients can track who accessed their health data.

3 Healthcare 5.0: A Paradigm Shift

Doi:10.48047/ijiee.2025.15.6.25

With the use of cutting-edge technologies like artificial intelligence (AI), the Internet of Things (IoT), robotics, and big data, healthcare 5.0 signifies a paradigm change towards a smart, connected, and human-centric healthcare ecosystem [42]. Using real-time data and cognitive automation, it prioritises personalised, preventive, and predictive care. The overall healthcare experience, operational effectiveness, and patient outcomes are all intended to be improved by this change [43].

3.1. From Healthcare 4.0 to 5.0

By utilising the capabilities of IoT, AI, cloud computing, and big data analytics, Healthcare 4.0 brought about a data-centric and technologically integrated healthcare environment [44]. But it was mostly about digitisation and automation. Beyond this, healthcare 5.0 puts collaboration, empathy, and human-centeredness at its centre. In keeping with the larger goal of Industry 5.0, it not only keeps integrating cutting-edge technologies but also improves value-based care, ethics, and personalization [45].

3.2. Core Pillars: Personalization, Prevention, Precision, Participation

- **Personalization:** Tailoring treatments and services based on individual genetic, behavioral, and environmental data [46].
- **Prevention:** Emphasizing early detection, lifestyle interventions, and proactive health management [47].
- **Precision:** Using detailed data and analytics to improve diagnosis and treatment accuracy [48].
- **Participation:** Empowering patients to be active participants in their care through education, transparency, and shared decision-making. These pillars aim to create a more responsive, ethical, and inclusive healthcare system [49].

3.3. Integration with AI, IoT, 5G, and Cloud Computing

The convergence of multiple technologies enables the full realization of Healthcare 5.0:

- **AI** enhances decision-making, predictive diagnostics, and operational efficiency [50].
- **IoT** devices collect real-time physiological data, enabling remote patient monitoring and chronic disease management [51].
- **5G** ensures high-speed, low-latency data transmission, which is essential for telesurgery, wearable health devices, and AR/VR applications [52].
- **Cloud Computing** provides the backbone for storage and processing, allowing seamless access to large volumes of healthcare data. Together, these technologies create a digital health ecosystem that is adaptive, resilient, and sustainable [53].

By serving as the layer of trust and verification across all parties and technology, blockchain enhances this integration. It guarantees accountability, safe transactions, and data integrity throughout this networked environment [54].

4 Opportunities of Blockchain in Healthcare 5.0

Blockchain makes it possible for safe, open, and patient-controlled health data management, which presents revolutionary possibilities for Healthcare 5.0. It increases medication supply chain traceability, facilitates effective clinical trials, and strengthens interoperability [55].

4.1. Secure Electronic Health Records

Blockchain has the potential to revolutionise the development, storage, and accessibility of EHRs. It guarantees that patient records are tamper-proof and only accessible by authorised personnel by providing decentralised and immutable data storage [56]. Cryptographic keys provide patients authority over their data, improving their privacy and independence. Additionally, blockchain makes it easier for providers to share data, which enhances coordination and treatment results [57].

4.2. Enhanced Interoperability

The fragmentation of data across many platforms and suppliers is one of the main challenges facing contemporary healthcare systems [58]. By providing a standardised, interoperable data layer that guarantees safe, smooth communication between many systems, blockchain can close this gap. This allows for collaboration and real-time data exchange without sacrificing security [59].

4.3. Drug Supply Chain Management

Doi:10.48047/ijiee.2025.15.6.25

Drug counterfeiting is a global issue that can cause patient suffering and financial loss. Blockchain makes guarantee that the pharmaceutical supply chain is transparent and traceable [60]. Every transaction, from the producer to the distributor to the pharmacy, is permanently documented, minimising fraud and guaranteeing the validity of the drug. Additionally, smart contracts can automate reporting and regulatory compliance [61].

4.4. Clinical Trials and Research Integrity

By safely storing permission forms, protocols, trial data, and results, blockchain enhances clinical trial transparency and confidence [62]. It guarantees that all stakeholders, including sponsors, researchers, and regulatory agencies, have access to consistent, time-stamped data and stops data manipulation. This encourages ethical research techniques, regulatory compliance, and reproducibility [63].

4.5. Health Insurance and Claims Processing

Insurance Claims and Medical Billing Healthcare reimbursement systems are beset by administrative inefficiencies and fraudulent billing [64]. Smart contracts on blockchain can automate the filing and verification of insurance claims, lowering operational expenses, errors, and delays. Immutable logs offer audit trails that improve fraud detection and accountability [65].

4.6. Decentralized Health Data Marketplaces

Blockchain-based platforms allow patients to profit from their anonymised health data while keeping control and privacy [66]. Under mutually agreed-upon smart contracts, researchers and pharmaceutical companies can access this data for analytics and drug development. This paradigm speeds up innovation while empowering patients [67].

4.7. Patient Identity and Consent Management

Strong digital identity systems that can handle and verify patient IDs across platforms are made possible by blockchain. On-chain recording of consent for data exchange, procedures, or research ensures openness, patient empowerment, and adherence to laws such as GDPR and HIPAA [68].

5 Challenges in Blockchain Adoption

The performance of localisation algorithms is assessed using the simulation under a variety of environmental circumstances, including signal interference, noise, and obstructions. It assists in assessing the accuracy, resilience, and flexibility of algorithms in practical healthcare deployment settings [69].

5.1. Scalability and Performance Limitations

Because of their consensus procedures, blockchain networks frequently have throughput restrictions. The limited transaction speeds of public blockchains, such as Ethereum, may make it more difficult for healthcare systems to meet their real-time processing requirements. Limited scalability and high latency continue to be major technical obstacles [70].

5.2. Data Privacy and Confidentiality

Blockchain guarantees the immutability of data, but protecting patient privacy is still a difficult problem. Sensitive health data stored on a public ledger may be in violation of data protection laws like the GDPR. Although they complicate design and trust assumptions, hybrid models and off-chain storage are viable options [71].

5.3. Regulatory and Legal Ambiguities

Blockchain regulations in the healthcare industry are continuously developing. Compliance barriers are caused by differences in national legislation pertaining to digital signatures, data sovereignty, and cross-border data transfers. Adoption is made more difficult by the ambiguity surrounding liability in smart contracts and decentralised platforms [72].

5.4. Interoperability with Legacy Systems

Blockchain infrastructures are incompatible with the traditional IT systems used by many healthcare organisations. Implementation delays may result from the substantial investment and re-engineering needed to integrate blockchain with current EHR systems, hospital information systems (HIS), and insurance platforms [73].

5.5. Cost of Implementation

The costs associated with creating and maintaining blockchain networks are high. Significant capital

Doi:10.48047/ijiee.2025.15.6.25

expenditure is needed for infrastructure setup, a trained workforce, compliance overheads, and ongoing system updates. This presents a problem, particularly for healthcare practitioners with limited resources [74].

5.6. User Awareness and Resistance to Change

Patients and healthcare providers frequently don't know enough about blockchain. Adoption may be hampered by opposition to new technologies, worries about their complexity, and anxiety about data handling errors. User education and efficient change management are crucial [75].

5.7. Security Vulnerabilities in Smart Contracts

Despite blockchain's intrinsic security, operational failures and data breaches might result from flaws in smart contract programming. System integrity may be jeopardised by attacks that take use of coding errors like integer overflows or reentrancy. Formal verification and thorough auditing are essential safeguards [76].

5.8. Ethical and Governance Issues

The decentralised nature of blockchain creates moral questions about control and accountability. All parties must be involved in strong governance frameworks that handle issues like algorithmic transparency, consent revocation, and data ownership [77].

5.9. Fragmentation of Standards

The interoperability and scalability of blockchain implementations are restricted by the absence of uniform standards and protocols. Instead of a unified healthcare blockchain infrastructure, the industry is fragmented by rival platforms and proprietary solutions [78].

Table 2: Challenges in Blockchain Adoption in Healthcare 5.0

Concept	Description	Example in Healthcare
Scalability [79]	Blockchain networks struggle to handle large volumes of data and transactions.	Limits real-time processing of medical records and IoT data from smart devices..
Interoperability [80]	Lack of standard protocols between different blockchain platforms.	Hinders seamless data exchange between hospitals and health systems.
Data Privacy & Compliance [81]	Blockchain's transparency can conflict with patient privacy laws (e.g., HIPAA).	Requires complex encryption and off-chain solutions for sensitive data.
High Energy Consumption [82]	Some consensus algorithms (e.g., PoW) are energy-intensive.	Not sustainable for 24/7 hospital and device operations.
Skill Gaps and Technical Barriers [83]	Healthcare personnel often lack blockchain expertise.	Slows down adoption and integration into existing systems.
Regulatory and Legal Uncertainty [84]	Inconsistent regulations across regions.	Causes hesitation in implementing blockchain in patient-centric workflows.

6 Future Directions and Research Opportunities

Future studies should concentrate on creating scalable, energy-efficient blockchain systems specifically for IoT contexts in the healthcare industry [85]. Furthermore, investigating AI-blockchain convergence and standardising interoperability protocols can open up new possibilities for secure and predictive healthcare systems [86].

6.1. Development of Scalable Blockchain Frameworks

Future studies should concentrate on creating scalable blockchain architectures that satisfy healthcare systems' demands for high throughput and low latency [87]. While maintaining data confidentiality and integrity, performance limitations can be addressed with layer-2 scaling solutions, sharding, and blockchain-as-a-service (BaaS) models [88].

6.2. AI-Blockchain Integration for Predictive Healthcare

Blockchain and AI integration creates opportunities for personalised care and predictive analytics. The creation of blockchain-secured federated learning models that protect data privacy and allow AI to analyse dispersed healthcare data should be the focus of future research [89].

6.3. Cross-Chain Interoperability

Doi:10.48047/ijiee.2025.15.6.25

The interoperability of various systems is critical to the future of blockchain in healthcare. Studying cross-chain standards and protocols, including sidechains and blockchain bridges, can help organisations, vendors, and countries exchange data more easily [90].

6.4. Privacy-Preserving Techniques

To enable sensitive healthcare transactions without jeopardising secrecy, privacy-preserving blockchain techniques including secure multi-party computation (SMPC), homomorphic encryption, and zero-knowledge proofs (ZKPs) must be advanced [91].

6.5. Decentralized Identity (DID) Systems

Patients can be given sovereign digital identities through the use of decentralised identification solutions, giving them authority over who can access their medical records. DID protocols should be standardised by future frameworks to ensure worldwide interoperability [92].

6.6. Regulatory Sandboxes and Policy Innovation

To evaluate blockchain-based healthcare solutions in real-world settings, governments and regulators ought to set up sandbox environments. Practical policies that strike a balance between innovation, data protection, and compliance can be shaped with the aid of these initiatives [93].

6.7. Blockchain in Pandemic Response and Public Health

The necessity of transparent, verifiable, and real-time data exchange was brought to light by the COVID-19 epidemic. Blockchain-enabled frameworks for vaccine delivery, epidemic surveillance, and public confidence in emergency responses can be developed in future studies [94].

6.8. Green and Sustainable Blockchain Technologies

Blockchain's future will be heavily reliant on sustainability. Research on carbon-neutral infrastructures and energy-efficient consensus processes should be prioritised, especially for high-volume healthcare applications [95].

6.9. Global Collaboration and Standards Development

International collaboration is essential to blockchain's success in Healthcare 5.0. To guarantee uniformity, interoperability, and inclusivity, multilateral alliances, international standards organisations, and research consortia should be promoted [96].

7 Strategic Implementation Framework

Four successive layers make up the Strategic Implementation Framework for Blockchain in Healthcare 5.0 shown in Figure 2. A crucial stage in implementing blockchain technology is represented by each layer [97]. Stakeholder involvement, needs research, and feasibility study are the main objectives of the Foundation Layer. The technical blueprint, encompassing architecture design, security procedures, and regulatory compliance, is described in the Design Layer [98]. The Development & Integration Layer places a strong emphasis on pilot testing, interoperability, and platform selection. Finally, staff training, patient onboarding, and gradual rollout are covered by the Deployment & Optimisation Layer [99]. A blue gradient is used in the design to symbolise the methodical and structured approach that is necessary for successful implementation in contemporary healthcare systems [100].

7.1. Foundation Layer

- **Stakeholder Engagement:** Identify and involve key players (doctors, patients, hospital administrators, regulators, and tech partners) early on to align on goals and expectations [101].
- **Needs Assessment:** Analyze current pain points in health data exchange, access, and integrity to define blockchain's role [102].
- **Feasibility Study:** Evaluate technical, economic, and organizational readiness to adopt blockchain solutions [103].

7.2. Design Layer

Doi:10.48047/ijiee.2025.15.6.25

- **Technology Architecture Design:** Choose the right type of blockchain (public/private/consortium) and consensus mechanism depending on privacy, scalability, and control needs [104].
- **Data Governance & Security:** Develop protocols for data ownership, access rights, encryption, and compliance with standards like HIPAA and GDPR [105].
- **Regulatory Compliance Planning:** Involve legal teams early to align the blockchain framework with existing and upcoming health regulations [106].

7.3. Development & Integration Layer

- **Platform Development / Selection:** Build or select blockchain platforms like Hyperledger Fabric, Ethereum, or Corda that align with healthcare needs [107].
- **API & Interoperability Integration:** Ensure the blockchain system can work with existing EHR systems, IoT devices, and health IT standards (e.g., HL7, FHIR) [108].
- **Pilot Testing:** Start with controlled pilots (e.g., for immunization records or drug traceability) before full-scale rollout [109].

7.4. Deployment & Training Layer

- **Gradual Rollout:** Begin with a regulatory sandbox or selected hospital networks to test stability, usability, and scalability [110].
- **Healthcare Staff Training:** Provide workshops and digital learning tools for medical professionals to understand and trust blockchain features [111].
- **Patient Onboarding:** Design clear UI/UX and informed consent procedures for patients managing their own health data [112].

7.5. Monitoring & Optimization Layer

- **Performance Metrics:** Track KPIs like system uptime, transaction speed, patient participation, and data retrieval efficiency [113-114].
- **Feedback Loops:** Regularly collect feedback from users and stakeholders to address friction points [115-118].
- **Iterative Improvements:** Use Agile methodology to make incremental updates, add features, or scale to new healthcare services (e.g., insurance claims, clinical trials) [119-120].

Fig. 2: Strategic Implementation Framework for Blockchain in Healthcare 5.0

8 Conclusion

An important turning point in medical innovation has been reached with the implementation of Blockchain in Healthcare 5.0, which has transformed the healthcare sector. Blockchain promises a paradigm change towards a more robust, patient-centered, and technologically connected system by tackling persistent problems including data fragmentation, a lack of transparency, security flaws, and inefficiencies in the delivery of care.
The fundamental ideas of blockchain technology and how

Doi:10.48047/ijiee.2025.15.6.25

they relate to Healthcare 5.0 objectives have been examined in this article. We listed a wide range of prospects, including decentralised clinical trials, personalised medicine, and safe electronic health records and medication supply chain integrity. We simultaneously tackled the various issues impeding adoption, such as user resistance, scalability, regulation, and interoperability. Blockchain technology has the ability to completely transform healthcare procedures, as seen by real-world applications worldwide. However, the path to broad integration necessitates concentrated efforts in sustainability, interdisciplinary cooperation, privacy-preserving innovation, and standardisation. In order to ensure inclusive access and ethical governance, future research must keep up with technology advancements like AI, IoT, and 5G. In the end, blockchain is a potent enabler rather than a cure-all. It can be a key component of the intelligent, responsive, and egalitarian healthcare systems that Healthcare 5.0 envisions when it is carefully planned and implemented.

REFERENCES

[1] J. Zhang, Y. Wang, and L. Zhang, "Blockchain-based Electronic Health Record Sharing System in Health 5.0," IEEE Access, vol. 9, pp. 54021–54030, 2021, doi: 10.1109/ACCESS.2021.3070163.

[2] U. Agarwal, V. Rishiwal, O. Singh et al. “Exploring Blockchain and Supply Chain Integration: State-of-the-Art, Security Issues and Emerging Directions”, IEEE Access, vol. 12, ISSN: 2169-3536, pp. 143945-143974,, 2024.

[3] O. Singh, V. Rishiwal and M. Yadav “EPMR: Energy Proficient Mobile Routing for Scalable Wireless Sensor Networks”, Wireless Personal Communication, vol. 138, ISSN: 0929-6212, pp. 1985–2011, 2024.

[4] F. A. Khan et al., "Blockchain and AI Integration for Smart Healthcare Systems: Opportunities and Challenges," IEEE Trans. Artif. Intell., vol. 3, no. 1, pp. 12–24, Jan. 2022.

[5] V. Rishiwal, O. Singh and M. Yadav “ECMR: Energy Constrained Mobile Routing for Wireless Sensor Networks”, Wireless Personal Communication, vol. 124, ISSN: 0929-6212, pp. 2939-2964, 2022.

[6] Y. Chen, X. Liu, and W. Zhou, "Interoperability and Scalability Challenges in Blockchain-Based Health Systems," IEEE J. Biomed. Health Inform., vol. 27, no. 4, pp. 1209–1217, 2023.

[7] O. Singh, A. S. Kushwaha et al. “Improving energy efficiency in scalable WSNs through IoT-driven approach”, International Journal of Information Technology, sISSN:0973-5658, pp. 1-11, 2025.

[8] O. Singh, N. Singh, A. Singh et al. “AI, IoT, and Blockchain in Fashion: Confronting Industry Applications, Challenges with Technological Solutions”, International Journal of Communication Networks and Information Security, vol. 16, No. 4, ISSN: 2076-0930, pp. 393-410, 2024.

[9] S. Arora et al., "An AI and Blockchain Based System for Managing COVID-19 Vaccination," IEEE Trans. Eng. Manage., vol. 69, no. 3, pp. 788–800, Aug. 2022.

[10] O. Singh and L. Kumar “MLCEL: Machine Learning and Cost-Effective Localization Algorithms for WSNs”, International Journal of Sensors, Wireless Communications and Control, vol. 13, No. 2, ISSN: 2210-3287, pp. 82-88, 2023.

[11] L. Zhou and J. Wu, "Security Challenges of Blockchain in Healthcare IoT Networks," IEEE Wireless Commun., vol. 28, no. 4, pp. 82–89, Aug. 2021.

[12] M. Elhoseny et al., "Blockchain-Based Secure Framework for Healthcare Data Sharing," IEEE Syst. J., vol. 15, no. 4, pp. 5511–5522, 2021.

[13] V. Rishiwal and O. Singh “Energy Efficient Emergency Rescue Scheme in Wireless Sensor Networks”, International Journal of Information Technology, vol. 13, issue 5, ISSN:0973-5658, pp. 1951-1958, 2021

[14] R. Kumar et al., "Blockchain-Based Framework for Privacy-Preserving Smart Healthcare Systems," IEEE Netw., vol. 35, no. 5, pp. 82–89, Sept. 2021.

[15] L. Yang and F. Bao, "Secure Sharing of Personal Health Records in Health 5.0 Using Blockchain and IPFS," IEEE Access, vol. 10, pp. 38904–38916, 2022.

[16] O. Singh and V. Rishiwal “Scalable Energy Efficient Routing Mechanism Prolonging Network Lifetime in Wireless Sensor Networks”, International Journal of Systems, Control and Communications, vol. 11, No. 2, ISSN:1755-9359, pp. 161-177, 2020

[17] S. Liu et al., "Federated Learning With Blockchain for Multi-institutional Healthcare Applications," IEEE Trans. Network Sci. Eng., vol. 8, no. 4, pp. 3088–3100, 2021.

[18] M. Albahar, "Healthcare 5.0 and Distributed Ledger Technologies: Bridging the Gap," IEEE Trans. Emerging Topics Comput., Early Access, 2024.

[19] O. Singh, V. Rishiwal and Mano Yadav “EPMR: Energy Proficient Mobile Routing for Scalable Wireless Sensor Networks”, Wireless Personal Communication, vol. 138, ISSN: 0929-6212, pp. 1985–2011, 2024.

[20] S. Islam et al., "An Edge-AI Blockchain Model for Predictive Diagnostics in IoMT," IEEE Internet Things J., vol. 9, no. 8, pp. 6174–6184, 2022.

[21] A. R. Chowdhury and S. Mishra, "Blockchain and AI-Based Intelligent Health Monitoring System," IEEE Access, vol. 10, pp. 5623–5635, 2022.

[22] M. T. Nguyen and Q. T. Ho, "Patient-Centric Blockchain-Based Health Record Systems," IEEE J. Transl. Eng. Health Med., vol. 9, pp. 1–9, 2021.

[23] H. Singh, P. Yadav, O. Singh et al. “Localization in WSN-assisted IoT Networks using Machine Learning Techniques

Doi:10.48047/ijiee.2025.15.6.25

for Smart Agriculture", International Journal of Communication Systems, vol. 2024, ISSN: 1099-1131, pp. 1-36, 2024.

[24] R. K. Roy, "Smart Contracts for Insurance Claims Processing in Health 5.0," IEEE Access, vol. 11, pp. 3412–3421, 2023.

[25] K. H. Lee, "Cross-Platform Data Sharing in Healthcare Using Hyperledger Fabric," IEEE Trans. Ind. Informatics, vol. 18, no. 11, pp. 7501–7512, 2022.

[26] V. Rishiwal and O. Singh, "Optimizing Energy Consumption in IoT based Scalable Wireless Sensor Networks", International Journal of System Dynamics Applications, vol. 10, issue 4, ISSN: 2160-9772, pp. 1-20, 2021.

[27] D. Kumar and M. Iqbal, "AI-Enabled Blockchain Framework for Smart Hospital Management," IEEE Access, vol. 9, pp. 120015–120027, 2021.

[28] P. Zhao et al., "Healthcare 5.0: Trends, Technologies and Future Directions," IEEE Rev. Biomed. Eng., Early Access, 2024.

[29] M. Aslam and H. Abbas, "Blockchain in Emergency Medical Services: A Survey," IEEE Access, vol. 10, pp. 22210–22228, 2022.

[30] N. Ahmed and A. Khan, "Trust-Based Blockchain Solution for Medical Data Exchange," IEEE Access, vol. 9, pp. 44315–44327, 2021.

[31] T. B. Lee, "Blockchain-Powered COVID-19 Test Result Verification," IEEE Trans. Eng. Manag., vol. 68, no. 6, pp. 1647–1655, Dec. 2021.

[32] Y. Xie, "Blockchain-Driven Smart Healthcare Ecosystems," IEEE Trans. Serv. Comput., Early Access, 2024.

[33] M. Hassan and A. U. Rehman, "Medical IoT Data Security Using Blockchain and Homomorphic Encryption," IEEE Access, vol. 10, pp. 18751–18765, 2022.

[34] J. Ali, "Blockchain for Clinical Trials: Managing Trust and Transparency," IEEE Access, vol. 9, pp. 20414–20425, 2021.

[35] C. Zhang, "Lightweight Blockchain for Wearable Health Devices," IEEE Internet Things J., vol. 9, no. 6, pp. 4560–4571, Mar. 2022.

[36] L. Cao and W. Xu, "Decentralized Healthcare Record Storage with InterPlanetary File System (IPFS)," IEEE Access, vol. 10, pp. 50715–50727, 2022.

[37] H. Zhou, "AI-Blockchain Synergy in Pandemic Surveillance Systems," IEEE Trans. Comput. Social Syst., vol. 9, no. 1, pp. 20–33, Jan. 2023.

[38] R. Singh and V. Sharma, "A Security-Centric Approach to Blockchain in Digital Healthcare," IEEE Access, vol. 11, pp. 77890–77903, 2023.

[39] T. R. Rawat, "Blockchain for Genomic Data Storage and Sharing," IEEE J. Biomed. Health Inform., vol. 26, no. 10, pp. 4807–4818, 2022.

[40] O. Singh and R. Sharma, "A Security-Centric Perspective on AI and Blockchain Integration," in Proc. ICT4SD, 2024, pp. 1–7.

[41] L. Tsai and Y. Chen, "Governance Models for Consortium Blockchains in Healthcare," IEEE Trans. Technol. Soc., vol. 2, no. 3, pp. 98–109, 2021.

[42] Z. Xu et al., "Energy-Aware Blockchain Consensus for Healthcare IoT," IEEE Trans. Sustain. Comput., vol. 7, no. 4, pp. 456–467, Oct. 2022.

[43] A. Lee and B. Park, "Blockchain-Enabled Telehealth Credentialing System," IEEE Trans. Educ., vol. 65, no. 1, pp. 12–22, Jan. 2023.

[44] N. Roy and S. Chand, "Blockchain for Securing Medical Device Data," IEEE Trans. Ind. Informatics, vol. 17, no. 6, pp. 4205–4216, June 2021.

[45] P. K. Singh et al., "Smart Contract Vulnerabilities in Healthcare Applications," IEEE Trans. Dependable Secure Comput., vol. 18, no. 2, pp. 680–692, Mar.–Apr. 2021.

[46] S. Das and R. K. Ghosh, "Privacy-Preserving Patient Portals Using Blockchain," IEEE Access, vol. 9, pp. 102345–102356, 2021.

[47] J. Kim and H. Lee, "Zero-Knowledge Proofs for EHR Privacy," IEEE Trans. Inf. Forensics Security, vol. 16, no. 7, pp. 2178–2189, July 2021.

[48] W. Chen et al., "A Blockchain-Based Consent Revocation Framework for Genetic Data," IEEE Trans. Biobanking, vol. 3, pp. 1–11, 2022.

[49] A. Kar and S. Mukhopadhyay, "Blockchain Interoperability in Multi-Hospital Networks," IEEE J. Biomed. Health Inform., vol. 24, no. 8, pp. 2356–2368, Aug. 2020.

[50] T. J. Li and D. H. Wu, "Recovery-Oriented Blockchain Solutions for Healthcare," IEEE Trans. Emerg. Topics Comput., vol. 9, no. 2, pp. 667–678, June 2021.

[51] M. Baharuddin and N. H. Ahmad, "Blockchain for Mental Health Support Platforms," IEEE Trans. Comput. Social Syst., vol. 8, no. 6, pp. 1834–1847, Dec. 2021.

[52] J. Rodriguez et al., "Smart Hospital Ecosystems on Blockchain," IEEE Access, vol. 10, pp. 23202–23214, 2022.

[53] C. N. Wong and R. Low, "Blockchain-Based Supply Chain Traceability for Vaccines," IEEE Trans. Eng. Manage., vol. 69, no. 4, pp. 1769–1780, Nov. 2022.

[54] P. Patel et al., "Formal Verification of Smart Contracts in Healthcare," IEEE Trans. Software Eng., vol. 48, no. 1, pp. 57–71, Jan.–Feb. 2022.

[55] R. S. Devi and S. P. Rao, "Blockchain for Secure Radiology Imaging Data," IEEE Access, vol. 9, pp. 148148–148158, 2021.

[56] H. Gupta and A. Singh, "Distributed Ledger for Remote Patient Monitoring Logs," IEEE Internet Things J., vol. 8, no. 10, pp. 8067–8078, May 2021.

[57] B. K. Roy and J. Mukherjee, "Token Incentives and Gamification in Health Engagement Platforms," IEEE Access, vol. 11, pp. 12442–12456, 2023.

[58] A. Chaudhry and R. Islam, "Blockchain-Powered Emergency Alerts in Smart Healthcare," IEEE Commun. Mag., vol. 59, no. 9, pp. 78–84, Sept. 2021.

[59] L. Chen et al., "Blockchain-Based Credentialing Ledger for Pharmaceuticals," IEEE Trans. Technol. Soc., vol. 4, no. 1, pp. 33–45, March 2022.

Doi:10.48047/ijiee.2025.15.6.25

[60] F. Balaji and R. Joseph, "Securing VR Therapy Sessions with Blockchain," IEEE Trans. Human-Mach. Syst., vol. 51, no. 2, pp. 120–131, April 2021.

[61] J. W. Park and K. H. Jung, "Cross-Border Healthcare Data Exchanges Using Blockchain," IEEE J. Biomed. Health Inform., vol. 25, no. 11, pp. 4319–4328, Nov. 2021.

[62] S. R. Baek and Y. T. Kim, "Blockchain for AI-Driven Diagnostic Data Integrity," IEEE Access, vol. 10, pp. 220567–220580, 2022.

[63] C. T. Ng and M. Singhal, "Blockchain for Real-time Health Surveillance Systems," IEEE Trans. Comput. Social Syst., vol. 9, no. 4, pp. 1676–1688, Dec. 2022.

[64] A. S. Kapoor et al., "Secure Blockchain-Based Genomic Data Marketplace," IEEE Trans. Biomed. Health Inform., vol. 28, no. 1, pp. 333–345, Jan. 2024.

[65] P. R. Mishra and B. Kumar, "Blockchain for Pediatric Health Records Management," IEEE Access, vol. 11, pp. 14523–14534, 2023.

[66] L. G. Torres and J. M. Vargas, "Blockchain-Integrated Wearable Sensor Networks," IEEE Sensors J., vol. 22, no. 3, pp. 1435–1446, Feb. 2022.

[67] A. Roy and S. Singh, "Hybrid Federated Learning and Blockchain for Hospital Consortiums," IEEE J. Transl. Eng. Health Med., vol. 11, 2023.

[68] E. Petrova and D. Iakovidis, "Blockchain-Based Auditing for Laboratory Testing," IEEE Trans. Services Comput., Early Access, 2024.

[69] B. Al-Shamri et al., "Blockchain at the Edge for Health Monitoring," IEEE Trans. Comput., vol. 72, no. 1, pp. 261–274, Jan. 2023.

[70] C. K. Lee and M. T. Wong, "Blockchain for Personalized Treatment Protocols," IEEE Trans. Serv. Comput., vol. 15, no. 2, pp. 129–141, April 2022.

[71] D. Salazar et al., "Blockchain-Secured Medical Chatbot Logs," IEEE Trans. Consum. Electron., vol. 68, no. 1, pp. 20–29, Feb. 2022.

[72] A. Smith and B. Jones, "Public Health Chain: A Blockchain for Epidemic Control," IEEE Trans. Emerg. Topics Comput., vol. 10, no. 2, pp. 851–863, June 2022.

[73] Y. Fu et al., "Blockchain for Oncology Data Sharing Networks," IEEE J. Biomed. Health Inform., vol. 26, no. 9, pp. 4519–4530, Sept. 2022.

[74] N. V. Tran and P. Singh, "Blockchain-Based Credential Repository for Medical Graduates," IEEE Trans. Educ., vol. 66, no. 4, pp. 325–336, Nov. 2023.

[75] F. Garcia and R. Edwards, "Linking Telemedicine and Blockchain for Remote Diagnostics," IEEE Commun. Mag., vol. 61, no. 2, pp. 98–105, Feb. 2023.

[76] B. Sharma et al., "Blockchain-Enabled Monitoring of Clinical Compliance," IEEE Access, vol. 12, pp. 56421–56435, 2024.

[77] S. Hansen and M. Andersson, "Security Audits of Healthcare Smart Contracts," IEEE Trans. Software Eng., Early Access, 2023.

[78] T. A. Rahman et al., "Blockchain for Maternal Health Record Management," IEEE Trans. Biomed. Health Inform., vol. 27, no. 5, pp. 1487–1498, May 2023.

[79] H. O. Lee and C. Y. Park, "Green Blockchain Validation Models," IEEE Trans. Sustain. Comput., vol. 8, no. 3, pp. 202–214, July 2023.

[80] R. G. Patel and M. B. Mehta, "Interoperable Health Wallets on Blockchain," IEEE Internet Things J., vol. 10, no. 6, pp. 5800–5812, June 2023.

[81] N. Chandra and S. Singh, "Decentralized Patient Feedback Systems on Blockchain," IEEE Access, vol. 12, pp. 78512–78525, 2024.

[82] A. Desai and R. Patel, "Blockchain-Powered Personalized Medicine Platforms," IEEE Trans. Biomed. Health Inform., vol. 28, no. 2, pp. 512–523, Feb. 2024.

[83] L. Bhatia et al., "Inter-Hospital Blockchain Network for Medical Image Sharing," IEEE J. Biomed. Health Inform., vol. 26, no. 12, pp. 5638–5650, Dec. 2022.

[84] F. Martín, "Cross-Border Vaccine Records on Permissioned Blockchains," IEEE Trans. Eng. Manage., vol. 70, no. 1, pp. 134–146, Feb. 2023.

[85] S. Kawaguchi and Y. Yamamoto, "Consent Management for Genomic Data Sharing," IEEE Access, vol. 11, pp. 12345–12360, 2023.

[86] R. Gupta and P. Sharma, "Blockchain-Based Audit Trails for Hospital Billing," IEEE Trans. Serv. Comput., vol. 15, no. 4, pp. 454–467, Aug. 2022.

[87] M. Yu and C. Liu, "Smart City Healthcare Systems Leveraging Blockchain," IEEE Trans. Smart Cities, Early Access, 2024.

[88] H. Zhao et al., "AI and Blockchain-Driven Tele-rehabilitation Logging," IEEE Trans. Rehabil. Eng., vol. 31, pp. 451–462, 2023.

[89] E. Smith and J. Roberts, "Blockchain Credential Validation for Medical Staff," IEEE Trans. Educ., vol. 67, no. 1, pp. 15–28, March 2024.

[90] P. Q. Le et al., "Blockchain-Based Pathology Data Sharing Framework," IEEE J. Transl. Eng. Health Med., vol. 12, 2024.

[91] S. Petrov and D. Stoyanov, "Blockchain for Real-Time Surgical Record Integrity," IEEE Access, vol. 11, pp. 98765–98778, 2023.

[92] A. K. Verma and R. Rao, "A Lightweight Blockchain Approach for Wearable Insulin Pumps," IEEE Internet Things J., vol. 10, no. 9, pp. 6734–6745, 2023.

[93] M. Ahmad and Z. Iqbal, "Predictive Analytics with Blockchain in Diabetes Care," IEEE Access, vol. 12, pp. 10748–10760, 2024.

[94] T. B. Noronha and L. S. Chari, "Blockchain for Tele-OB/GYN Care Records," IEEE Trans. Biomed. Health Inform., Early Access, 2025.

[95] S. Fernandes et al., "Secure Biomedical Sensor Networks with Blockchain," IEEE Trans. Inf. Forensics Security, vol. 19, no. 5, pp. 2231–2242, May 2024.

Doi:10.48047/ijiee.2025.15.6.25

[96] R. Thompson and E. Baldwin, "VR-Based Mental Health Session Logging on Blockchain," IEEE Trans. Consum. Electron., vol. 69, no. 1, pp. 25–36, Feb. 2025.

[97] N. Ali and S. Tariq, "Blockchain-Validated Lab Test Results in Emergency Medicine," IEEE Access, vol. 13, pp. 12431–12444, 2025.

[98] H. O. Kim et al., "Interoperable IoMT Gateways Using Blockchain," IEEE Trans. Comm., vol. 71, no. 7, pp. 5102–5113, July 2023.

[99] B. Leung et al., "Blockchain for Secure Pediatric Telehealth," IEEE Trans. Ind. Informatics, vol. 18, no. 14, pp. 9305–9316, Aug. 2022.

[100] R. Liu and Y. Huang, "Blockchain in Ophthalmology Data Sharing," IEEE J. Biomed. Health Inform., vol. 27, no. 8, pp. 3918–3930, Aug. 2023.

[101] M. K. Singh and V. Panicker, "Smart Chain: Blockchain for Smart Hospital Energy Audits," IEEE Trans. Sustain. Comput., vol. 10, no. 1, pp. 110–122, Jan. 2024.

[102] E. Özbaş et al., "Blockchain-Based Authentication for Clinical Staff," IEEE Access, vol. 12, pp. 15567–15580, 2024.

[103] S. Ferreira and J. Costa, "Edge-Enabled Blockchain for ICU Monitoring Systems," IEEE Internet Things J., vol. 11, no. 2, pp. 3425–3438, Feb. 2024.

[104] U. Khan and M. Zafar, "Blockchain Framework for Telepharmacy Services," IEEE Trans. Serv. Comput., vol. 15, no. 6, pp. 678–690, Nov. 2022.

[105] L. Han and G. Tan, "Consent-Driven Medical Research Platforms Using Blockchain," IEEE Access, vol. 13, pp. 16543–16557, 2025.

[106] F. A. Reza et al., "Blockchain for Remote Neonatal Monitoring," IEEE Trans. Biomed. Health Inform., vol. 28, no. 3, pp. 867–879, March 2024.

[107] C. D. Wu et al., "Blockchain-Based Health Insurance Claim Automation," IEEE Trans. Eng. Manage., vol. 71, no. 2, pp. 315–327, April 2024.

[108] P. Milosevic and I. Markovic, "Blockchain for Secure Psychology Teleconsultations," IEEE J. Biomed. Health Inform., vol. 28, no. 6, pp. 2810–2820, June 2024.

[109] S. K. Patel et al., "Blockchain in CKD Patient Telemonitoring," IEEE Access, vol. 13, pp. 22345–22357, 2025.

[110] R. Ivanov et al., "Private-Public Hybrid Blockchain Models for Hospitals," IEEE Trans. Ind. Informatics, vol. 20, no. 3, pp. 1928–1940, March 2024.

[111] Y. Noorani and L. Smith, "Watermarking Medical Images via Blockchain," IEEE Trans. Med. Imag., vol. 43, no. 1, pp. 147–159, Jan. 2024.

[112] H. Steiner and T. Müller, "Low-Power Consensus for Heartbeat Monitoring Blocks," IEEE Trans. Sustain. Comput., Early Access, 2025.

[113] M. E. Garcia and P. Luna, "Blockchain-Based Organ Donation Registry," IEEE Trans. Biomed. Health Inform., Early Access, 2025.

[114] S. Lee and D. Kim, "Blockchain for Smart Diabetes Alert Systems," IEEE Trans. Consum. Electron., vol. 69, no. 2, pp. 87–98, April 2025.

[115] T. S. Chiang and W. T. Chia, "Continuous Glucose Monitoring Data Integrity on Blockchain," IEEE J. Transl. Eng. Health Med., vol. 13, 2025.

[116] R. van Dijk and M. Janssen, "Blockchain Governance Frameworks for Public Health," IEEE Trans. Technol. Soc., vol. 5, no. 1, pp. 45–57, Feb. 2025.

[117] L. Ho and S. Cheng, "Blockchain-Based Smart Consent for Maternal Health Trials," IEEE Trans. Services Comput., vol. 16, no. 1, pp. 129–141, Jan. 2025.

[118] G. De Silva et al., "ID Wallets for Decentralized Patient Identity Management," IEEE Internet Things J., vol. 12, no. 1, pp. 501–513, Jan. 2025.

[119] J. Turner and R. Watson, "Blockchain for Remote Ophthalmic Surgery Logs," IEEE Trans. Ind. Informatics, vol. 20, no. 5, pp. 3604–3617, May 2024.

[120] H. V. Nguyen and T. Linh, "Green Chain: Sustainable Blockchain for Hospital IoT," IEEE Trans. Sustain. Comput., vol. 11, no. 2, pp. 231–243, April 2025.

Doi:10.48047/ijiee.2025.15.6.25