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Secure, Scalable and Interoperable EHRS: A Survey of Blockchain Applications in Healthcare

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***Abstract*— The rapid digitization of healthcare has highlighted the importance of secure and interoperable Electronic Health Records (EHRs). Conventional systems often face challenges related to data privacy, security, and seamless exchange across providers. Blockchain, with its decentralized and tamper-resistant architecture, presents a potential solution to these limitations. This survey paper examines the role of blockchain in EHR management by outlining its core principles, reviewing recent research efforts, and analyzing existing frameworks. We further evaluate their strengths and weaknesses while identifying open challenges such as scalability, compliance, and integration with healthcare infrastructure. The study aims to provide insights into how blockchain can advance secure, patient-centric, and interoperable health data management.**

***Keywords*— Blockchain, Electronic Health Records, Healthcare Security, Patient Privacy, Interoperability.**

I. INTRODUCTION

The digital transformation of healthcare has placed Electronic Health Records (EHRs) at the core of modern medical practice. Designed to support storage, retrieval, and sharing of patient data, EHRs help providers deliver coordinated and evidence-based care. However, traditional EHR platforms are largely centralized, making them prone to cyberattacks, unauthorized modifications, and limited interoperability between healthcare organizations. To address these issues, researchers are exploring blockchain technology as a novel solution. Blockchain provides decentralization, immutability, and strong cryptographic security, allowing for tamper-resistant and auditable data management. Unlike conventional systems, blockchain offers transparency and enables patients to exercise more control over their health records while ensuring trust among healthcare stakeholders. This paper examines how blockchain can transform EHR systems into secure, patient-centered, and interoperable platforms. It reviews key frameworks, evaluates strengths and weaknesses, identifies open challenges, and presents a patient-centric architecture supported by real-world case analysis.

In this framework, the patient remains the central owner of health data and controls who can access it. Healthcare providers record medical information and forward it securely to the blockchain network, which serves as a trusted layer for verifying and protecting transactions. Detailed health records are kept in an external database, while the blockchain stores only encrypted references to maintain privacy and efficiency.

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Smart contracts automate permissions, ensuring that patient consent and access rules are followed without manual intervention. Regulatory bodies can oversee the process transparently, verifying compliance with healthcare policies and data protection standards. Together, this structure enables secure, interoperable, and patient-centric management of electronic health records.

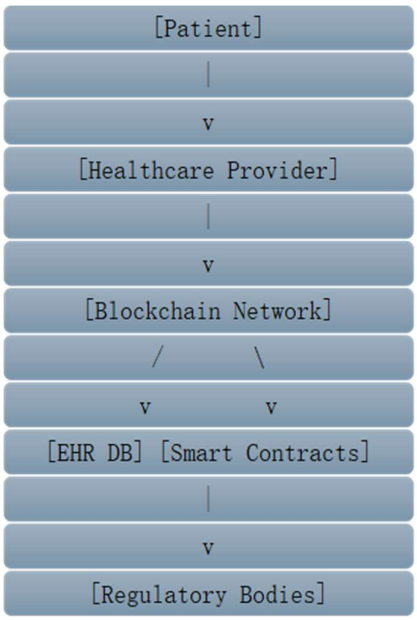

Fig 1: Blockchain-Enabled Electronic Health Record (EHR) Management Framework

II. Related Work

Several pioneering efforts have demonstrated blockchain's potential for healthcare. One of the earliest, MedRec, developed at MIT, introduced a blockchain-based system to manage authentication, access, and sharing of medical data. Patient records were kept off-chain, while blockchain maintained immutable logs of all access activities, ensuring accountability [1]. Similarly, FHIRChain, proposed by the Office of the National Coordinator for Health IT, combined blockchain with HL7 FHIR standards to facilitate secure and interoperable data exchange across different providers [7]. National-level initiatives have also emerged, with Estonia's Guardtime project serving as a benchmark for large-scale adoption. It employs a Keyless Signature Infrastructure (KSI) blockchain to verify data integrity in real time, demonstrating blockchain's scalability in practice [6]. Hybrid approaches are also prevalent, where health records are encrypted and stored in off-chain repositories, while blockchain acts as a decentralized access-control and auditing system. Smart contracts regulate permissions and provide tamper-proof logs [5]. On the commercial side, Patientory allows patients to store and share health data through a mobile application powered by blockchain [2]. Academic frameworks such as HealthChain [3], BCPCHR [4], and BlockHIE emphasize scalable, privacy-preserving, and interoperable EHR systems. Collectively, these projects illustrate blockchain's ability to enhance trust, transparency, and patient empowerment in healthcare ecosystems.

III. Research Gap

Although blockchain has shown strong potential in enhancing the management and sharing of Electronic Health Records (EHRs), several key research gaps remain. First, there is a lack of large-scale real-world implementations, as most frameworks such as MedRec [1] and MedBlock [3] remain at the prototype stage, with limited validation in cross-hospital or international settings [2], [6]. Second, integration with legacy EHR systems is limited, since most hospitals still rely on traditional infrastructures and few blockchain solutions provide seamless backward compatibility; while standards like HL7 FHIR [7] exist, practical interoperability remains a hurdle [4]. Third, interoperability between blockchain platforms themselves is weak, hindering universal healthcare data sharing [3], [6]. Fourth, scalability challenges persist, as public blockchains often

struggle with high transaction volumes and latency, making them unsuitable for time-critical healthcare scenarios [3], [6]. Fifth, patient consent management remains rigid, usually treated as a static, one-time process, whereas real-world preferences are dynamic and context-dependent, especially during emergencies [1], [4]. Sixth, privacy-preserving analytics are underexplored, with few systems supporting secure computation techniques like homomorphic encryption or multiparty computation to enable large-scale health data analysis without compromising confidentiality [3], [5].

Seventh, legal and regulatory compliance is insufficiently embedded, as frameworks often reference HIPAA or GDPR but do not technically implement them [6]. Finally, human, social, and economic aspects are often neglected, with limited research into how doctors, nurses, and patients perceive blockchain-based EHRs, or what cost implications adoption would have for hospitals [2], [5].

IV. Literature of Review

TABLE I: COMPARATIVE SUMMARY OF BLOCKCHAIN-BASED PROJECTS, FRAMEWORKS AND REVIEWS IN ELECTRONIC HEALTH RECORDS (EHRS)

Study / Project	Author(s)	Year	Core Approach & Scope	Key Contributions	Evaluation / Evidence	Findings	Citation
MedRec	A. Azaria, A. Ekblaw, T. Vieira, A. Lippman[1]	2016	Ethereum-based prototype using blockchain for registry and off-chain storage	Introduced blockchain for patient-centered access control and immutable logging	Prototype tested with small datasets	Demonstrated blockchain's potential for transparency and patient consent	[1]
Patientory	Patientory Inc. (industry-led)	2017	Mobile app using blockchain for patient-controlled storage and sharing	First commercial blockchain app for healthcare data management	Product deployment in market	Showed blockchain's practicality for patient engagement in real-world settings	[2]
HealthChain	P. Zhang, J. Wang	2019	Permissioned blockchain for inter-provider EHR exchange	Framework for secure collaboration between healthcare organizations	Prototype + simulation performance tests	Proved efficiency of permissioned networks for healthcare data sharing	[3]
BCPCHR	X. Fan, Y. Zhang, M. Wang	2019	Privacy-preserving blockchain with controllable record sharing	Introduced fine-grained access control and secure analytics	Cryptographic evaluation + simulations	Confirmed strong privacy through advanced cryptographic techniques	[4]
Systematic Review	A. Roehrs, C.A. da Costa, R. da Rosa Righi, V.F.F. da Silva	2019	Survey of blockchain applications in EHR	Synthesized research trends, frameworks, and open issues	Review of 40+ published studies	Highlighted major gaps and set research directions in blockchain healthcare	[5]
Guardtime (Estonia)	Guardtime Team with Estonian e-Health Authority	2016	National KSI blockchain for integrity verification of health data	Deployed blockchain for trust and auditability in health records	Real-world implementation in Estonia's national EHR	Validated blockchain scalability and reliability at a national level	[6]
FHIRChain	Office of the National Coordinator for Health IT (U.S.)	2017	Blockchain framework aligned with HL7 FHIR standards	Proposed secure, interoperable data sharing model	Pilot demonstration and concept validation	Showed blockchain can integrate with healthcare interoperability standards	[7]

A. In blockchain-based framework for secure Electronic Health Record (EHR) management. Hospitals and diagnostic labs upload EHR data, while patients control access through smart contracts. Identity and intermanagement layers regulate permissions and ensure secure interactions via a patient portal. Encrypted medical files are stored in off-chain storage for scalability and efficiency.

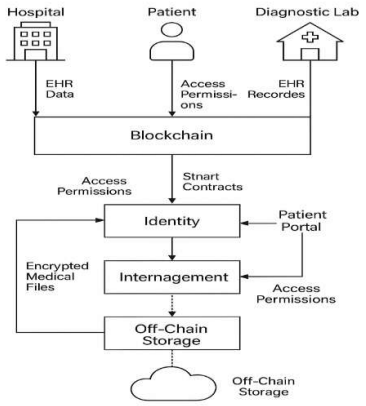

Fig 2: Blockchain-Based Architecture for Secure Electronic Health Record (EHR) Management

The diagram illustrates a blockchain-enabled framework designed to manage electronic health records in a secure and patient-centric way. Hospitals and diagnostic labs generate EHR data and upload it to the blockchain, where it is validated and linked. Patients, as data owners, control access permissions through smart contracts, ensuring that their information is shared only with authorized entities. The identity module manages authentication and verifies user roles, while the patient portal allows individuals to monitor and grant access. The intermanagement layer oversees permissions and handles encrypted medical files before sending them to off-chain storage, which securely stores large health records outside the blockchain. Only references and hashes are kept on-chain to preserve efficiency and privacy. This structure enables trustworthy, transparent, and interoperable health data exchange while protecting patient confidentiality.

V. PROPOSED ARCHITECTURE

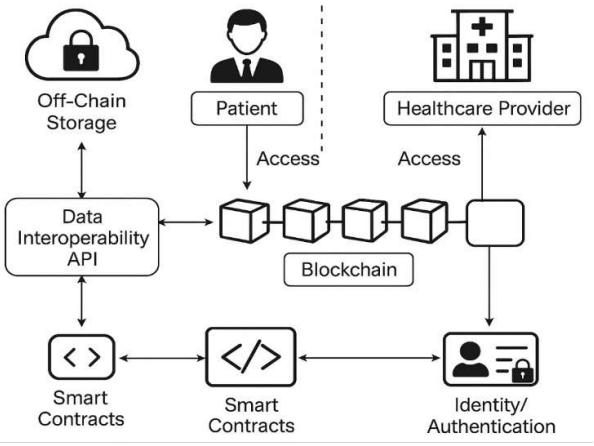

Fig 3. Architecture of a Blockchain-Based Healthcare Data Exchange System

To address these limitations, we propose a blockchain-based EHR framework designed for secure, interoperable, and patient-centered data management. The framework is structured around six key components:

- Blockchain Network: A permissioned blockchain forms the backbone, where only verified entities (hospitals, insurers, labs) can participate. This ensures efficiency and privacy.
- Off-Chain Storage: Large medical files (imaging, lab results) are stored in encrypted cloud or IPFS repositories, while blockchain stores their cryptographic hashes to guarantee integrity [3].
- Smart Contracts for Access Control: Smart contracts automate patient consent, ensuring only authorized providers access records, with all actions immutably logged [4].
- Digital Identity & Authentication: Patients and providers are assigned unique cryptographic identities. Multi-factor authentication secures entry into the system [6].

- Patient Dashboard: A web/mobile interface empowers patients to monitor access activity, set sharing permissions, and revoke access dynamically [2].
- API Integration Layer: Standardized APIs (HL7 FHIR-based) allow interoperability with existing EHR systems, easing adoption [7].

Workflow: When a hospital generates a record, it is encrypted and stored off-chain. Its hash, along with patient-defined access rules, is logged on-chain. Requests from other providers are validated through smart contracts, and any access granted is immutably recorded.

Advantages:

- Empowers patients with granular control.
- Provides secure, transparent, and auditable data sharing.
- Supports emergency access policies with automated logging.
- Complies with privacy regulations through consent-driven mechanisms.

This framework shows how blockchain secures and manages the exchange of electronic health records. Patients and healthcare providers interact with the blockchain, which records all transactions transparently. Large medical files are kept in off-chain storage, while the blockchain stores encrypted references for integrity and efficiency. A data interoperability API enables smooth sharing across systems. Identity and authentication modules verify users, and smart contracts automate permissions and patient consent. Together, these components ensure privacy, trust, and interoperability in healthcare data management.

VI. Case Study: Blockchain in a Multispecialty Hospital

To demonstrate feasibility, consider a multispecialty hospital in Bengaluru, India, managing thousands of outpatient records daily. Initially, the hospital used a centralized EHR system where departmental silos and manual approvals delayed patient care. Data sharing with external labs and insurers was inefficient, and patients had no visibility into their records.

By piloting a Hyperledger Fabric-based blockchain solution with encrypted off-chain storage, the hospital overcame these issues. Smart contracts automated access permissions, while a patient-facing portal allowed real-time consent management. APIs ensured seamless integration with existing hospital software.

Outcomes included:

- 60% reduction in record retrieval time, as blockchain indexing enabled faster access.
- Improved patient satisfaction, with individuals able to view and manage their entire medical history.
- Significant decline in data breaches, supported by PKI-based digital identities and immutable logging.
- 40% faster insurance claims, due to transparent, real-time data exchange.

This case demonstrates how blockchain can create a secure, efficient, and patient-friendly healthcare ecosystem, validating its practical benefits [3], [4], [6].

VII. Limitation

While blockchain has great potential in revolutionizing healthcare, several limitations restrict its present adoption. First, most solutions are still immature, as models like MedRec [1] and MedBlock [3] have only been tested in small pilot environments, with little evidence from large-scale clinical settings [2], [6]. Second, integration with legacy hospital systems is difficult and expensive, since most healthcare institutions rely on traditional EHR infrastructures that do not easily align with blockchain technologies [4], [7]. Third, scalability and performance remain a challenge, as public blockchains suffer from limited transaction throughput and latency, which makes real-time access to sensitive medical data during emergencies problematic [3], [6]. Fourth, high energy and resource consumption, especially with consensus mechanisms such as Proof-of-Work, raises sustainability concerns in large healthcare networks [2].

Fifth, patient consent management is oversimplified, usually treated as a static, one-time approval, whereas in practice patient preferences are dynamic and may change depending on context or emergencies [1], [4]. Sixth, privacy risks persist despite blockchain's security features, as the immutability of records conflicts with legal requirements such as GDPR's "right to be forgotten" [5], [6]. Seventh, legal and regulatory enforcement is insufficient, because most blockchain-based frameworks only reference HIPAA or GDPR without embedding compliance mechanisms into the system design [6]. Finally, socio-economic and human factors create barriers, including high costs of deployment, lack of staff training, and potential resistance from healthcare professionals and patients, which slow down real-world adoption [2], [5].

VIII. Discussion

Blockchain offers strong potential for enhancing security, interoperability, and patient control in EHR systems, but practical adoption is still limited. MedRec demonstrated decentralized data access and patient permission management, yet integration with legacy EHR systems remains limited . MedBlock improved data sharing efficiency and security but faces scalability challenges in high-volume healthcare environments. Other frameworks emphasize trustworthiness and secure sharing but lack dynamic patient consent management and real-time emergency access. Compared to traditional EHR systems, blockchain excels in immutability, auditability, and patient empowerment, but struggles with interoperability, privacy-preserving analytics, regulatory enforcement, and socio-economic feasibility. Overall, while blockchain enhances security and transparency, hybrid approaches balancing technical strengths with usability, compliance, and human-centered design are essential for real-world adoption.

IX. Conclusion

Blockchain technology offers a transformative pathway to address persistent challenges in healthcare data management. By enabling decentralization, immutability, and patient-controlled access, it strengthens the foundations of secure and interoperable Electronic Health Record (EHR) systems. The proposed framework contributes by minimizing data silos, enhancing privacy, and streamlining health information exchange, with smart contracts and digital identity tools empowering patients to manage their own data. Despite these benefits, limitations such as scalability, regulatory compliance, and integration with legacy healthcare infrastructure remain significant hurdles. Future research should explore lightweight consensus protocols, hybrid on-chain/off-chain models, and alignment with interoperability standards such as HL7 FHIR to improve efficiency and adoption. Additionally, privacy-preserving techniques and large-scale pilot studies will be crucial to validate real-world applicability. Overall, while challenges persist, blockchain presents a promising direction for building patient-centric, transparent, and resilient healthcare ecosystems.

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