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A Survey on Blockchain-Driven Allograft Management: A Secure Approach to Data Provenance

Hemalatha K[1], Aishwarya R[2], Bhoomika B S[3], Kruthika K M[4], Madhavi S[5]
[1]Assistant Professor, Dept of CSE, Sapthagiri college of Engineering
[2, 3, 4, 5]Dept of CSE, Sapthagiri College of Engineering

Abstract: The demand for organ transplants is growing rapidly, yet the existing systems for organ donation face significant challenges, including lack of transparency, delays, and fraudulent activities. This paper explores a novel approach to address these issues by leveraging blockchain technology. Blockchain offers a decentralized, secure, and tamper-proof environment that can improve the efficiency and reliability of the organ donation process. By incorporating smart contracts and distributed ledger principles, the proposed system ensures that donor and recipient data are securely recorded, access is appropriately regulated, and organ matching and allocation are carried out transparently. The integration of blockchain also enhances trust and minimizes administrative overhead, making the donation process more accountable and streamlined. The study also outlines a conceptual framework for implementing this technology and highlights the potential impact on reducing illegal organ trade and ensuring ethical compliance. The study also explores how blockchain could help in maintaining a nationwide or even global donor registry that is both interoperable and scalable. In doing so, it opens avenues for real-time updates, faster allocation decisions, and the potential to curb illegal organ trafficking. Through a conceptual prototype and system design, the paper illustrates the feasibility of this approach and sets the foundation for future research and real-world implementation.

I. INTRODUCTION

In the realm of transplant medicine, the secure, efficient, and transparent management of allograft (donor tissue) data is essential to safeguarding patient outcomes and maintaining ethical integrity. However, conventional centralized systems often fall short in ensuring data provenance, leaving room for manipulation, fraud, and operational inefficiencies. This survey explores a blockchain-based approach to allograft management that addresses these critical concerns by leveraging the decentralized, immutable, and transparent nature of blockchain technology. The significance of this problem domain stems from the life-critical nature of organ and tissue transplantation, where any lapse in data integrity or traceability can result in irreversible harm. Current centralized systems are vulnerable to unauthorized access, tampering, and lack the ability to offer reliable end-to-end traceability. In contrast, blockchain technology inherently provides a secured ledger that records each transaction in a verifiable and tamper-proof manner— making it a suitable solution for transplant ecosystems that demand trust, compliance, and security.

Extensive research have been conducted in this space. For instance, the Indriya system employs Hyperledger Fabric for organ matching but lacks urgency-based prioritization and suffers from performance bottlenecks under high throughput. Similarly, ProvChain and SciBlock focus on data provenance in healthcare and scientific workflows but are limited in scalability or real-world applicability. Unlike these approaches, our survey evaluates solutions that not only support smart contract automation but also integrate role-based access, secure donor- patient matching, and detailed traceability from registration to transplantation. Our approach stands apart by emphasizing both functional automation and ethical compliance through fine-grained access control and real-time auditability. The methodology of this survey involved comprehensive literature analysis of recent blockchain-based systems for healthcare and organ donation, particularly focusing on their architecture, algorithms, limitations, and performance. We then synthesized findings to identify gaps in current solutions, benchmarked them against our proposed Ethereum-based smart contract architecture, and drew insights regarding security, scalability, and usability.

Our findings highlight that blockchain enables verifiable data lineage and automates transplant processes while enhancing stakeholder trust. Through different approaches, our study found that Ethereum- based smart contracts offer a balance of automation and auditability, outperforming legacy systems in traceability and fraud resistance, though requiring optimization for gas costs and scalability.

From these results, we conclude that blockchain can revolutionize allograft management by offering a decentralized, transparent, and secure infrastructure.

II. BACKGROUND

A. Problem Description

Allograft transplantation plays a role in saving lives but involves complex processes including donor registration, recipient matching, organ transportation, and surgery. Current centralized systems are prone to data breaches, manipulation, and lack of transparency, compromising both patient safety and regulatory compliance. In 2023, over 133 million individuals were affected by data breaches in healthcare systems, underlining the need for a secure and verifiable solution. To overcome these challenges, the proposed system adopts a blockchain-based approach using Ethereum smart contracts. Blockchain ensures immutability, decentralization, and tamper-proof data recording, enhancing traceability from donor to recipient. The system comprises three layers—actors, front end, and blockchain back end— and automates allograft workflows including registration, verification, matching, donation, transportation, and transplantation. Each action is recorded immutably on-chain, with cryptographic authentication and access control ensuring data integrity and security.

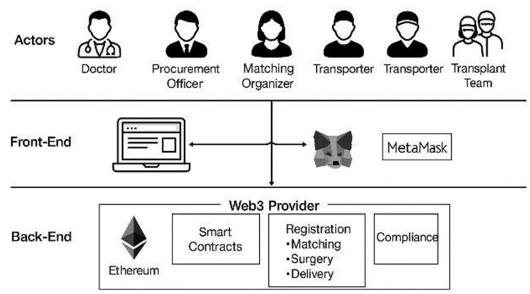


Fig1.System Overview of Blockchain-Based Organ Donation

B. Adversary Model:

The adversary model considers both internal threats (e.g., unauthorized actors manipulating data) and external attacks (e.g., hacking attempts). Security is enforced through role-based access using smart contract modifiers and digital signatures via Metamask wallets, preventing impersonation or unauthorized actions. Every transaction is authenticated and stored immutably, making tampering or manipulation detectable and accountable. This model is grounded in real-world vulnerabilities observed in healthcare systems and ensures regulatory transparency, traceability, and data provenance throughout the transplant process.

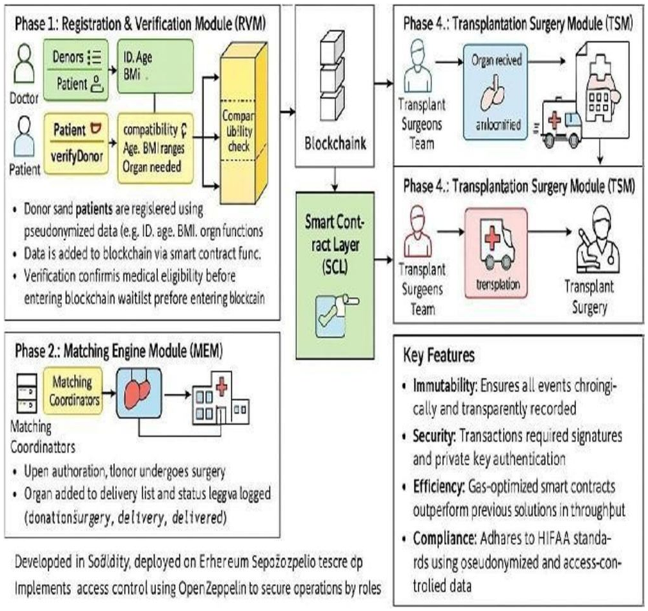
III. LITERATURE SURVEY

1) Indriya: Building a Secure and Transparent Organ Donation System with Hyperledger Fabric [2] (2023) : Decentralized organ donation system developed using Hyperledger Fabric 2.2 on AWS Managed Blockchain. The platform uses smart contracts to handle donor and patient registration, organ matching, and transplant finalization, all accessed via a web-based client interface. Performance was benchmarked using Hyperledger Caliper, achieving up to ~508 TPS for reads. It ensures transparency and traceability in the donation process.
   The advantage is operational efficiency through decentralized automatio
   The limitation lies in the absence of urgency-based prioritization and performance degradation beyond 400 TPS
2) ProvChain A Blockchain-Based Data Provenance Architecture [3] (2017): Blockchain-based data provenance framework integrated with ownCloud. It uses a three-layer architecture—cloud storage, a provenance database, and blockchain—and employs Merkle trees and Chainpoint via the Tierion API to anchor hashes. This allows secure, real-time auditing without centralized trust.
   The advantage is its ability to provide tamper-evident provenance in decentralized environments.
   The limitation is its dependency on external APIs and reduced scalability during high-frequency operations.
3) Blockchain-Based Management for Organ Donation and Transplantation [4] (2022): created a blockchain system for automating organ donation using a private Ethereum network and Solidity contracts. It facilitates donor-recipient registration, matching, organ tracking, and logistics, with deterministic algorithms based on age, BMI, blood type, and organ type. The system improves transparency and reduces manual intervention.
   The advantage is automated process flow with blockchain-backed security.
   The limitation is its lack of advanced clinical parameters like HLA compatibility or urgency-based logic

4) KIDNER – A Worldwide Decentralised Matching System for Kidney Transplants [5] (2017): Decentralized system built on Ethereum for kidney transplant matching using encrypted certificates and smart contracts. It employs multi-signature verification and ensures data anonymity. While designed to facilitate global matching, it remains a proof-of-concept.
   The advantage is secure, decentralized, anonymized matching.
   The limitation is its lack of real-world deployment, algorithm documentation, and scalability.
5) Decentralized Organ Donation and Transplantation Using Blockchain Technology [6] (2024): Proposed a private Ethereum-based organ transplant platform using Solidity smart contracts. It supports donor approval, registration, and attribute-based matching, offering transparent, tamper-resistant workflows. The system ensures fast matching and auditability.
   Its advantage is improved speed and fraud prevention.
   The limitation is the lack of urgency handling and limited privacy due to full transaction visibility.
6) Blockchain and Electronic Healthcare Records: [7] (2018):Blockchain solution for electronic healthcare records (EHR), giving patients control over data via private keys while enabling transparent audit trails. The system builds on the MedRec framework, allowing real-time, permissioned sharing across healthcare providers. The advantage is enhanced patient control and fraud reduction.
   The limitation includes privacy concerns due to blockchain transparency and challenges related to user digital literacy and data control resistance from institutions.
7) SciChain-Trustworthy Scientific Data Provenance [8]: Targets high-performance computing environments with its POST (Proof-of- Scalable Traceability) consensus algorithm. It validates data in memory across compute nodes and falls back to persistent shared storage. Supporting over one million transactions and 1,024 nodes, it outperforms conventional blockchains in latency and throughput.
   Its advantage lies in highly scalable and efficient consensus tailored for HPC.
   The limitation is the lack of smart contract support and high memory overhead at small scales.
8) Blockchain-based Approach for Data Accountability and Provenance Tracking: Developed a GDPR-compliant data accountability system using Ethereum smart contracts with Event- Condition-Action (ECA) rules. It supports subject-, data-, and controller-specific policies with anonymized identities and nonce unlinkability. The platform ensures auditability and consent enforcement
   The advantage is fine-grained privacy control with transparent provenance tracking.
   The limitation involves high transaction costs and scalability limitations on public blockchains.
9) SciBlock- A Blockchain-Based Tamper-Proof Non-Repudiable Storage for Scientific Workflow Provenance [9] : provenance- tracking system for scientific workflows on a private Ethereum network with Proof-of-Authority consensus. It supports on- chain provenance recording and off-chain querying using derivation graphs and Bloom filters, with invalidation for outdated records.
   The main advantage is tamper-proof, non-repudiable recordkeeping, The limitation is vulnerability during data ingestion and performance degradation at larger scales.
10) FineGrained, Secure and Efficient Data Provenance on Blockchain Systems [10]: a Hyperledger-based fine-grained provenance system that captures smart contract execution history with lightweight APIs. It uses a skip list index for efficient queries and minimizes storage overhead.
   The advantage is efficient, detailed provenance logging for runtime events
   The limitation is its limited compatibility outside Hyperledger and potential slowdowns with complex queries under high transaction loads.

IV. METHODOLOGY

1) *Phase of Registration and Verification:* All of the interactions between doctors, patients, and donors during the registration and verification stages are . A doctor enrolls donors and patients in the smart contract, triggering an event of registration. After that, to verify eligibility, the teams from the organ procurement organization and the transplant will examine the patient’s and donor’s data, respectively. After validation, the patient and donor will be officially placed on the waiting list within the system.
2) *Phase of Matching Patients and Donors:* In this stage, the system will look through patient and donor data to find compatible matches based on blood type, compatibility with allografts, and other health criteria. When a suitable match is found, an event triggers the announcement of the match being.



Developed in Solidity, deployed on Ethereum Sepolia testnet; Implements access control using OpenZeppelin to secure operations by roles

Fig2.Process Flow

3) Actors layer: This layer contains the major actors in the suggested solution, such as doctors, procurement organizers, organ match organizers, transporters, members of the transplant team, and surgeons. Every entity is authorized by the system administrator to access the system, and each actor has specific responsibilities in the system according to their designation.
4) Front-end layer: This layer connects the back-end layers to the actors layer. It provides an interface for managing and accessing data. It makes it possible for authorized actors to carry out the system's designated tasks. The actors' web browsers can easily read and use the readable code of the front-end layer. Each function generates a transaction, and actors sign it using a blockchain signer, such as Metamask.
5) Back-end layer: The layer manages and stores trans actions and storage data for allograft transplantation. The key components of this layer are Ethereum, which hosts the smart contract, and a Web3 provider, which enables users to communicate with the blockchain. The blockchain permanently records each event, logs, and transactions. The back-end layer secures and preserves data integrity via access control encryption methods. It is in charge of retrieving and modifying information. All three layers of the architecture offer excellent information management regarding allograft transplantation, which increases trust and transparency. The proposed architecture workflow ensures that each actor interacts using their web browser and digital wallets like Metamask. Each transaction that requires addition or updation of data requires cryptographic authentication of private key and actor confirmation. While data retrieval does not require any gas, it still requires a digital wallet connection for retrieving actor-specific data. Digital wallets connection with blockchain often requires a password or another authentication method, which makes the overall process more secure and tamper-proof. This ensures that the individuals who are authorized can interact with the blockchain.

V. FUTURE WORKS

1) Integrate IoT devices for real-time tracking of allograft conditions.
2) Enhance scalability using Layer 2 blockchain solutions.
3) Use AI for predictive analytics in graft viability and patient matching.
4) Implement Zero-Knowledge Proofs for secure and private data sharing.
5) Conduct pilot testing in hospitals to validate system performance.
6) Ensure regulatory compliance with medical data standards (e.g., HIPAA).
7) Create user-friendly interfaces and training for medical staff adoption

VI. CONCLUSION

The transformative potential of blockchain technology in revolutionizing allograft and organ transplant management. Traditional centralized systems suffer from security lapses, inefficiencies, and lack of transparency—challenges that blockchain can effectively mitigate. By leveraging Ethereum-based smart contracts and a layered architecture, the proposed system ensures secure registration, verification, matching, and transplantation of organs, with full traceability and tamper-proof data provenance. The comparative analysis of existing blockchain-based solutions reveals that while several frameworks offer transparency and automation, most fall short in areas such as urgency-based matching, scalability, and privacy. The system proposed by introducing fine- grained access controls, role- based permissions, and cryptographic verification, significantly enhancing trust, auditability, and compliance. Overall, the integration of blockchain into allograft workflows promises to increase trust among stakeholders, reduce fraud, streamline operations, and enable ethical and accountable organ donation practices. This conceptual foundation paves the way for future research, real-world testing, and policy-aligned implementations in healthcare environments.

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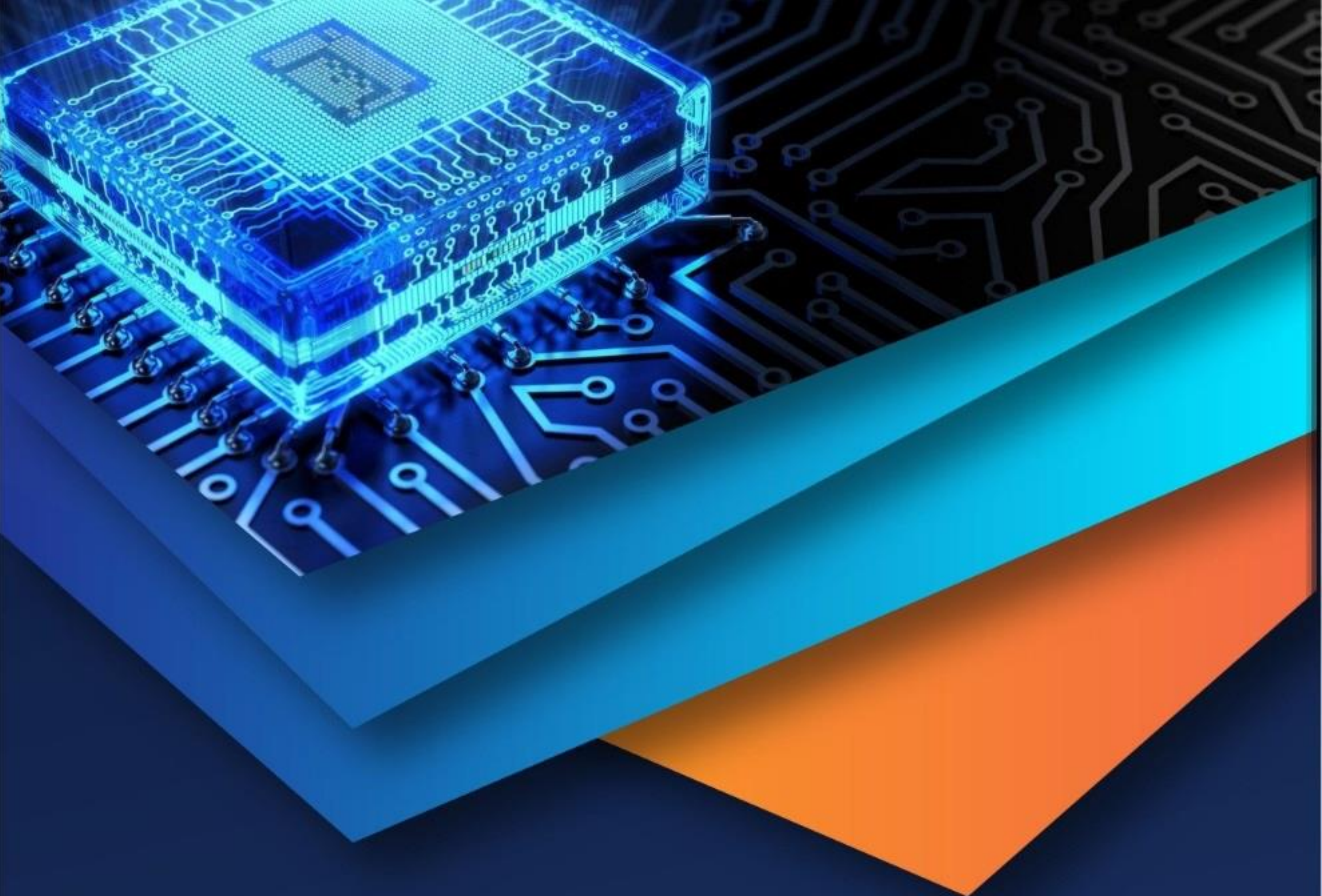

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