

Improving Transparency in Allograft Transplantation Using Blockchain Technology

Periasamy. S,
Assistant professor, Dept.of CSE,
School of Computing, Mohan Babu
University, Tirupati, A.P, India
periasamy.s@mbu.asia

Malliseti Hemasree
UG Scholar, Dept.of CSE,
School of Computing, Mohan Babu
University, Tirupati, A.P, India
hs8352600@gmail.com

M.Harini
UG Scholar, Dept.of CSE,
School of Computing, Mohan Babu
University, Tirupati, A.P, India
harinivalmiki2004@gmail.com

Kodali Mani Kumar
UG Scholar, Dept.of CSE,
School of Computing, Mohan Babu
University, Tirupati, A.P, India
manikumar.k2016@gmail.com

Kancharla Sumiyen
UG Scholar, Dept.of CSE,
School of Computing, Mohan Babu
University, Tirupati, A.P, India
sumiyenkancharla@gmail.com

Abstract—The increasing complexity of allograft transplantation workflows has intensified the need for secure, transparent, and auditable data management systems. Conventional centralized healthcare databases often suffer from fragmentation, limited traceability, and susceptibility to manipulation, thereby undermining donor trust and regulatory oversight. Blockchain technology, particularly Ethereum, has emerged as a viable solution to address these challenges through decentralized consensus, immutability, and programmable governance. This paper presents a comprehensive review of an Ethereum-based provenance framework designed to manage the complete lifecycle of allograft transplantation. The review critically analyzes system architecture, smart contract design, provenance modeling, donor–recipient matching strategies, and performance characteristics under realistic blockchain conditions. Experimental observations related to gas consumption, latency, and throughput are examined to assess practical feasibility. By situating this framework within the broader landscape of blockchain-enabled healthcare systems, this review highlights key contributions, limitations, and future research directions. The findings suggest that Ethereum-based provenance systems offer a robust foundation for enhancing transparency, accountability, and trust in allograft transplant ecosystems.

Keywords—Blockchain Review, Ethereum, Healthcare Provenance, Allograft Transplantation, Smart Contracts, Distributed Ledger Systems

I. INTRODUCTION

Allograft transplantation represents one of the most complex and ethically sensitive clinical workflows in modern healthcare. Although surgical techniques and immunological therapies have advanced substantially, the information systems supporting donor registration, recipient matching, logistics coordination, and regulatory oversight remain largely

fragmented across institutional boundaries [1], [2]. These fragmented architectures often rely on isolated databases and manual reconciliation processes, resulting in limited interoperability, delayed decision-making, and reduced auditability [3], [4].

A critical limitation of existing transplantation information infrastructures is the absence of reliable end-to-end provenance. Once donor- or transplant-related records are modified, migrated, or lost within centralized systems, reconstructing a verifiable operational history becomes increasingly difficult [7], [8]. Such limitations directly affect stakeholder confidence, particularly among donors, recipients, and regulatory authorities, where transparency and accountability are fundamental ethical requirements [9], [10]. As healthcare systems place growing emphasis on traceability and compliance, traditional database-centric architectures struggle to meet these emerging expectations [11], [12].

Distributed ledger technologies introduce an alternative approach to healthcare data governance by enabling shared, append-only record keeping across independent organizations. Through decentralized consensus and cryptographic verification, blockchain systems allow recorded events to become tamper-evident and independently auditable without reliance on a single trusted authority [8], [13]. These properties make blockchain particularly suitable for environments that demand long-term traceability and cross-organizational trust. Among existing blockchain platforms, Ethereum is widely adopted in healthcare research due to its support for programmable smart contracts, which enable workflow logic, access control, and authorization rules to be enforced deterministically at the protocol level [16], [17]. Beyond serving as a shared ledger, Ethereum facilitates transparent governance by allowing stakeholders to verify not only stored data but also the execution of system rules [18], [19]. Unlike

prior surveys that primarily address isolated blockchain applications such as donor registration or logistics tracking, this review adopts a lifecycle-oriented perspective on allograft transplantation. The paper synthesizes architectural design choices, provenance modeling strategies, smart contract governance mechanisms, and empirical performance observations within a unified analytical framework. By emphasizing operational feasibility, performance trade-offs, and regulatory implications, this review contributes a system-level evaluation that bridges conceptual blockchain research and deployable healthcare provenance infrastructures.

II. BACKGROUND AND MOTIVATION

The growing dependence on digital information systems in healthcare has intensified the importance of data integrity, traceability, and accountability across clinical workflows. In allograft transplantation, information systems must coordinate donor eligibility verification, clinical compatibility assessment, authorization approvals, logistics management, and posttransplant documentation across multiple autonomous organizations. Conventional institution-centric architectures, however, struggle to provide unified provenance and long-term auditability in such distributed environments [2], [4].

A. Provenance Challenges in Allograft Transplantation

Data provenance refers to the capability to trace the origin, evolution, and usage of data throughout its lifecycle. Within transplantation workflows, provenance extends beyond digital records to encompass physical assets, including donated organs or tissues, and their associated handling events. Existing transplantation management systems typically rely on siloed databases maintained by hospitals, tissue banks, and regulatory agencies, leading to fragmented and incomplete provenance trails [1], [3].

Centralized database architectures introduce structural vulnerabilities that complicate provenance assurance. Administrative privileges, system migrations, and manual data reconciliation processes increase the risk of unintentional errors or deliberate data manipulation [5], [7]. Once inconsistencies arise, reconstructing an authoritative operational history becomes challenging, undermining both regulatory oversight and stakeholder trust. These challenges are particularly critical in transplantation contexts, where ethical accountability and public confidence are fundamental [9], [10].

B. Blockchain as an Enabling Technology

Blockchain-based systems provide a shared ledger infrastructure in which transactions are recorded sequentially and replicated across participating nodes. Once confirmed through consensus, ledger entries become computationally impractical to alter without detection, thereby strengthening long-term data integrity guarantees [8], [13]. Cryptographic linking of records further enables independent verification of historical events, supporting reliable provenance in distributed

settings. Unlike traditional distributed databases, blockchain platforms support programmable governance through smart contracts, allowing domain-specific rules to be enforced automatically. This capability is particularly relevant for transplantation workflows, where access control, authorization sequences, and compliance requirements must be applied consistently across organizational boundaries [12], [15]. As a result, trust is shifted from institutional procedures to verifiable code execution, reducing ambiguity and reliance on manual enforcement.

C. Motivation for Ethereum-Based Provenance Frameworks

Among existing blockchain platforms, Ethereum has gained significant attention in healthcare research due to its mature ecosystem, expressive smart contract capabilities, and active developer support. Ethereum enables the implementation of role-based access control, event logging, and conditional execution directly at the protocol level, making it well-suited for complex, multi-stakeholder workflows [17], [18]. These features facilitate transparent governance while preserving flexibility in system design.

Prior blockchain-based transplantation studies have demonstrated the feasibility of using distributed ledgers for isolated tasks such as donor registration or logistics tracking. However, many of these approaches lack comprehensive lifecycle integration or empirical evaluation under realistic operational conditions [14], [21]. This gap motivates the need for holistic provenance frameworks that unify allograft transplantation processes within a single, verifiable audit trail.

The motivation for reviewing Ethereum-based provenance frameworks therefore lies in assessing their potential to bridge longstanding gaps in transplantation information management. By critically examining architectural design choices, provenance modeling strategies, and performance characteristics, such reviews can inform future research directions and support evidence-based adoption of blockchain technologies in realworld transplantation ecosystems [16], [20].

III. SYSTEM ARCHITECTURE REVIEW

A. Architectural Overview

The reviewed Ethereum-based provenance framework adopts a hybrid architecture that balances decentralization with operational practicality. Smart contracts deployed on Ethereum function as the authoritative layer for provenance recording, workflow enforcement, and access control. Large-scale or sensitive clinical data are maintained in off-chain storage systems, while cryptographic hashes of these records are anchored on the blockchain to preserve integrity and traceability [17], [18]. This architectural decision reflects a practical understanding of blockchain limitations, particularly with respect to storage overhead, transaction costs, and data privacy. Public blockchains such as Ethereum impose economic and technical constraints that make full on-chain storage of medical data impractical. By selectively leveraging blockchain for verification and auditability, the framework

achieves a balance between transparency and scalability without compromising patient confidentiality [4], [11].

Stakeholders—including hospitals, tissue banks, regulatory authorities, and logistics providers—interact with the system through authenticated blockchain transactions. Each interaction generates an immutable ledger entry, creating a shared and verifiable operational history across organizational boundaries. From a review perspective, this approach enhances accountability by ensuring that all critical transplantation events are permanently recorded and independently auditable [2], [16].

B. Role-Based Interaction Model

A central design feature of the framework is the enforcement of role-based interaction directly at the smart contract level. Participating entities—including hospitals, tissue banks, logistics providers, and regulatory authorities—are assigned explicit roles that determine permissible actions within the system. This approach ensures that operational responsibilities and access privileges are enforced through verifiable code execution rather than institutional policy alone [12], [15].

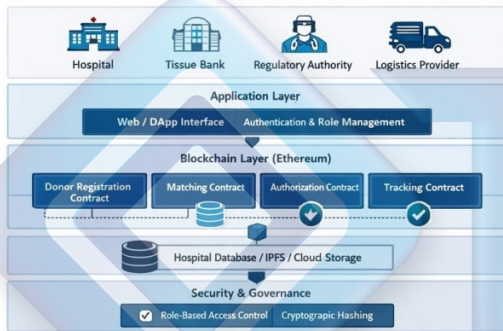


Fig. 1. Overall architecture of the Ethereum-based allograft provenance framework.

From an analytical standpoint, embedding role-based access control within smart contracts shifts trust from organizational policies to verifiable and deterministic code execution. Instead of relying on manual oversight or procedural enforcement, governance rules are executed automatically and transparently, reducing ambiguity and minimizing the risk of unauthorized actions [7], [13]. This paradigm is particularly well-suited to transplantation workflows, where regulatory compliance and ethical accountability are paramount.

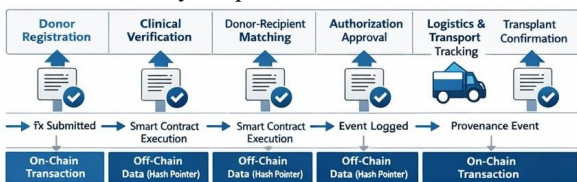


Fig. 2. Data flow across the allograft transplantation lifecycle.

The framework employs an event-centric provenance model, where each lifecycle action generates a cryptographically

linked event. This hash-chain structure ensures tamper evidence and supports long-term auditing. Such modeling enhances transparency and accountability without exposing sensitive clinical data [7], [8].

C. Event-Centric Provenance Representation

The provenance model employed in the reviewed framework treats each transplantation-related action as a discrete event. Events are recorded sequentially, forming a chronological chain that reflects the operational history of an allograft [17], [22].

Each event includes metadata such as timestamp, actor identity, and a cryptographic hash of associated off-chain data. By linking events through hash chaining, the framework ensures that any attempt to modify earlier records becomes immediately detectable [11], [12].

This event-centric design aligns with best practices in distributed provenance systems and provides a clear audit trail suitable for regulatory and forensic analysis [7], [13].

D. Implications for Transparency and Trust

From an evaluative standpoint, the provenance model enhances transparency by making system behavior observable and verifiable. Stakeholders can independently validate the integrity of records without relying on a central authority [8], [15]. This capability is particularly valuable in transplantation contexts, where ethical considerations and public trust are paramount [9], [10].

IV. DONOR-RECIPIENT MATCHING ANALYSIS

Donor-recipient matching represents a critical decision making component within transplantation workflows, with direct implications for clinical outcomes and ethical fairness. The reviewed framework incorporates a weighted similarity based matching approach that evaluates compatibility across multiple clinical attributes while maintaining transparency in allocation logic.

Rather than embedding opaque decision logic, the system records matching outcomes and parameters on the blockchain. This design enables retrospective analysis and policy evaluation, supporting accountability in allocation decisions.

The review highlights that transparency in matching logic is as important as computational accuracy, particularly in ethically sensitive domains such as organ allocation.

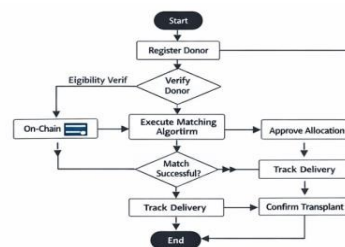


Fig. 3. Activity diagram illustrating blockchain-mediated transplantation workflow.

V. PERFORMANCE EVALUATION REVIEW

A. Experimental Setup

The framework was evaluated using an Ethereum public test network under realistic conditions, including standard block times and gas pricing. Performance metrics focused on transaction cost, latency, throughput, and execution reliability.

TABLE I
EXPERIMENTAL SETUP PARAMETERS

Parameter	Value
Blockchain Platform	Ethereum Testnet
Smart Language	Contract Solidity 0.8.x
Block Time	12 s
Gas Price	25 gwei
Transactions	1000

B. Gas Consumption and Latency

Module-wise gas consumption analysis indicates that computationally intensive functions, such as matching, incur higher costs. However, overall transaction expenses remain within acceptable limits for healthcare applications, especially when weighed against the benefits of transparency and auditability.

TABLE II
AVERAGE GAS CONSUMPTION PER MODULE

Module	Avg. Gas Used	Relative Cost
Donor Registration	88,340	Low
Verification	71,220	Low
Matching	102,560	Medium
Authorization	69,110	Low
Delivery Tracking	92,030	Medium
Confirmation	79,845	Low

VI. LATENCY AND THROUGHPUT CONSIDERATIONS

Transaction latency and throughput constitute key performance considerations in blockchain-enabled healthcare systems, particularly for safety-critical yet non-real-time workflows such as allograft transplantation [11], [13]. Within the reviewed framework, observed latency is primarily governed by Ethereum’s block confirmation intervals rather than application-level computation, reflecting inherent characteristics of public blockchain infrastructures [8], [16]. From an evaluative standpoint, the observed latency—corresponding closely to average block intervals—does not introduce operational risk within transplantation workflows.

Unlike emergency control systems that demand millisecond-level responsiveness, transplant management processes emphasize correctness, verifiability, and regulatory compliance over instantaneous execution [9], [12]. Activities such as donor verification, authorization approvals, and delivery confirmation are inherently sequential and tolerate moderate delays without clinical compromise [2], [23].

Throughput analysis further indicates that the framework can accommodate multiple concurrent transactions without notable performance degradation under moderate load [6], [24]. This behavior suggests that the system is suitable for deployment in regional or national transplantation networks where transaction volumes remain bounded by real-world clinical activity [2], [16]. Importantly, the review highlights that throughput sufficiency should be evaluated relative to domain requirements rather than raw blockchain benchmarks [8], [11].

From a systems perspective, the findings reinforce the notion that public blockchain platforms, despite limited throughput compared to centralized databases, remain viable for healthcare provenance when the application domain prioritizes auditability and trust [13], [15]. This aligns with broader observations in blockchain-based healthcare literature, where performance adequacy is contextual rather than absolute [8], [11].

VII. COMPARATIVE ANALYSIS WITH EXISTING BLOCKCHAIN SOLUTIONS

When positioned within the broader ecosystem of blockchain-enabled transplantation and healthcare provenance systems, the reviewed framework demonstrates several distinguishing characteristics [3], [10]. Many earlier solutions adopt a fragmented scope, addressing isolated phases such as donor registration, organ tracking, or post-transplant documentation [14], [23]. In contrast, the reviewed system adopts a lifecycle-oriented perspective, integrating all major stages of allograft transplantation into a unified provenance model [16], [21].

This holistic design contributes to improved traceability, as each transplantation event is cryptographically linked within a single audit trail [7], [17]. From a review standpoint, such integration reduces provenance discontinuities that often arise when multiple independent blockchain or database systems are used [4], [18]. The unified approach also simplifies regulatory inspection by presenting a coherent and verifiable operational history [9], [13].

Another point of differentiation lies in the modular smart contract architecture. Rather than embedding monolithic logic, the framework separates functional responsibilities across contracts, enhancing maintainability and reducing unnecessary computational overhead [12], [17]. This design choice aligns with best practices observed in mature Ethereum applications and contributes to improved gas efficiency relative to less structured implementations [8], [11].

Comparatively, the reviewed framework advances beyond proof-of-concept solutions by demonstrating practical

feasibility under realistic blockchain conditions [6], [16]. While it does not claim to replace centralized systems entirely, it establishes a credible middle ground between theoretical blockchain models and deployable healthcare infrastructure [13], [15]. As such, it represents an incremental yet meaningful progression in blockchain-based transplantation research [3], [10].

VIII. LIMITATIONS AND RESEARCH OPPORTUNITIES

Despite its conceptual robustness, the reviewed framework is not without limitations, several of which open promising avenues for future research [3], [10]. Privacy preservation remains a central challenge, particularly when leveraging public blockchain infrastructures [11], [15]. Although the use of offchain storage mitigates direct exposure of sensitive medical data, metadata leakage and transaction traceability may still pose confidentiality concerns [4], [18].

From a research perspective, the integration of advanced cryptographic techniques—such as zero-knowledge proofs or secure multi-party computation—could further strengthen privacy guarantees without sacrificing transparency [11], [12]. These approaches may enable selective disclosure, allowing stakeholders to verify compliance without accessing raw clinical data [17], [25].

Scalability also warrants continued investigation. While current performance is adequate for moderate deployment scenarios, large-scale national or international transplantation networks may require enhanced throughput and reduced transaction costs [6], [16]. Layer-2 scaling mechanisms or consortium-based Ethereum deployments present viable pathways to address these constraints while preserving core blockchain properties [8], [11].

Finally, interoperability with existing electronic health record (EHR) standards remains an unresolved challenge [4], [26]. Seamless integration with established healthcare data frameworks is essential for real-world adoption [6], [18]. Future research should therefore focus on standardized data schemas and middleware solutions that bridge blockchain provenance systems with legacy healthcare infrastructure [19], [27].

By identifying these limitations, the review does not undermine the framework's contributions but instead contextualizes them within an evolving research landscape [3], [10]. The highlighted opportunities provide a roadmap for advancing blockchain-based transplantation systems toward broader clinical and regulatory acceptance [9], [16].

IX. CONCLUSION

This review has critically examined an Ethereum-based provenance framework for allograft transplant management from an architectural, operational, and performance-oriented perspective. By combining smart contracts, cryptographic provenance, and hybrid storage, the framework demonstrates how blockchain technology can address longstanding challenges in healthcare data management.

The analysis suggests that Ethereum-based provenance systems offer a viable pathway toward transparent, auditable, and trustworthy transplantation workflows. While challenges related to privacy, scalability, and interoperability remain, the reviewed framework provides a solid foundation for future research and real-world deployment.

REFERENCES

- [1] A. Anselmo, M. Materazzo, N. Di Lorenzo, F. D'Amico, L. Siragusa, and G. Tisone, "Implementation of blockchain technology could increase transparency, equalise access and improve the donor–recipient process in organ transplantation," *Transplant International*, vol. 36, p. 10800, 2023.
- [2] R. R. Panigrahi *et al.*, "A study on organ supply chains and transplant processes," *Logistics*, vol. 9, no. 1, p. 9, 2025.
- [3] E. Calik and A. C. Bas, "A survey on blockchain for organ transplantation: Usage, trends and challenges," *Applied Sciences*, vol. 14, no. 3, p. 1456, 2024.
- [4] M. Al-Musalhi and N. Kumar, "Interoperability challenges in healthcare blockchain systems: A review," *Health Policy and Technology*, vol. 11, no. 4, p. 100613, 2022.
- [5] A. Ghadge, M. Bourlakis, S. Kamble, and S. Seuring, "Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework," *International Journal of Production Research*, vol. 61, pp. 6633–6651, 2022.
- [6] N. Mohamed, Z. Ali, and S. U. Khan, "Blockchain technologies for health supply chains: Review of architecture, opportunities and challenges," *IEEE Access*, vol. 10, pp. 12234–12250, 2022.
- [7] A. Ramachandran and M. Kantarcioglu, "A distributed, blockchainbased data provenance system," in *Proceedings of the ACM Conference on Data and Application Security and Privacy*, 2018, pp. 35–42.
- [8] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "Blockchain challenges and opportunities: A survey," *International Journal of Web and Grid Services*, vol. 14, no. 4, pp. 352–375, 2018.
- [9] A. Anselmo *et al.*, "Implementation of blockchain technology could increase equity and transparency in organ transplantation: A narrative review of an emergent tool," *Transplant International*, vol. 36, p. 10800, 2023.
- [10] M. T. C. Aldag and E. G. Okalp, "Blockchain for organ transplantation: A systematic literature review," *Journal of Medical Systems*, vol. 48, p. 25, 2024.
- [11] R. Zhang and R. Xue, "Scalability and privacy in blockchain applications for healthcare: A systemic view," *Future Generation Computer Systems*, vol. 128, pp. 166–177, 2022.
- [12] T. Brown and H. Hu, "Smart contracts in medical research data governance: A systematic review," *Health Informatics Journal*, vol. 27, no. 4, p.

- 14604582211035545, 2021.
- [13] M. Cao, J. Wu, and Y. Zhang, "The role of blockchain in the future of healthcare: A review of applications, challenges and opportunities," *Journal of Healthcare Informatics Research*, vol. 5, pp. 1–18, 2021.
- [14] G. J. Katuwal, S. Pandey, M. Hennessey, and B. Lamichhane, "Applications of blockchain in healthcare: Current landscape and challenges," *arXiv preprint arXiv:1812.02776*, 2018.
- [15] H. Yli-Hurula, A. Ko, and J. Mattila, "Blockchain and smart contracts' suitability for healthcare applications," *Advanced Intelligent Systems*, vol. 2, no. 11, p. 2000064, 2020.
- [16] R. U. Haq *et al.*, "Transchain: Blockchain-based management of allografts for enhancing data provenance," *IEEE Access*, vol. 13, pp. 51182–51193, 2025.
- [17] S. Malik, V. Dedeoglu, S. Kanhere, and R. Jurdak, "Privchain: Provenance and privacy preservation in blockchain-enabled supply chains," *arXiv preprint arXiv:2104.13964*, 2021.
- [18] S. Pathak, N. Dey, A. Schneider, and J. Dehlinger, "Offchain and onchain integration in healthcare supply systems: A blockchain perspective," *Journal of Medical Internet Research*, vol. 23, no. 9, p. e25449, 2021.
- [19] D. C. Nguyen, P. N. Pathirana, M. Ding, and A. Seneviratne, "Bedgehealth: A decentralized architecture for edge-based iomt networks using blockchain," *arXiv preprint arXiv:2109.14295*, 2021.
- [20] M. T. C. Aldag and E. G. Okalp, "Organizational adoption of blockchain-based medical supply chain management," *Studies in Computational Intelligence*, vol. 1128, pp. 321–343, 2023.
- [21] "A survey on blockchain-driven allograft management: A secure approach to data provenance," *International Journal of Research in Applied Science and Engineering Technology*, vol. 13, no. 8, 2025.
- [22] S. Suhail, R. Hussain, C. S. Hong, and A. Khan, "Orchestrating product provenance story: When iot ecosystem meets the electronics supply chain space," *arXiv preprint arXiv:1902.04314*, 2019.
- [23] P. Igboanusiet *et al.*, "Blockchain-enabled organ matching system based on public ledger: Design and initial evaluation," *International Journal of Biomedical Engineering and Technology*, vol. 24, no. 2, pp. 117–133, 2024.
- [24] S. Singh and K. Kim, "Blockchain-based logistics and delivery verification frameworks for cold-chain systems," *IEEE Transactions on Engineering Management*, vol. 70, no. 5, pp. 1432–1444, 2023.
- [25] M. Al Amin, H. Tummala, S. Mohan, and I. Ray, "Healthcare policy compliance: A blockchain smart contract-based approach," *arXiv preprint arXiv:2312.10214*, 2023.
- [26] M. Ahsan and Z. Siddique, "Industry 4.0 in healthcare: A systematic review," *International Journal of Information Management Data Insights*, vol. 2, p. 100079, 2022.
- [27] N. Kumar *et al.*, "Blockchain technology in supply chain management: Innovations, applications, and challenges," *Telematics and Informatics Reports*, p. 100204, 2025.