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Blockchain-Based Drug Traceability for Counterfeit Detection

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Abstract: Counterfeit medicines have become a major challenge in pharmaceutical supply chains, leading to serious risks for patient safety and healthcare reliability. Traditional medicine tracking systems mainly rely on centralized databases and static QR verification methods, which are vulnerable to data manipulation and QR duplication attacks. To address these issues, this paper proposes a Blockchain-Based Drug Traceability and Intelligent Counterfeit Detection System that enhances medicine verification using blockchain technology and software-level counterfeit detection mechanisms.

The proposed system integrates blockchain-based medicine registration, QR code verification, ownership transfer tracking, scan history monitoring, and suspicious activity detection to improve transparency and traceability across the pharmaceutical supply chain. Medicines are registered and stored securely using smart contracts, while QR codes are generated for product verification. In addition, the system identifies possible counterfeit activities through duplicate scan detection, ownership validation, repeated scan monitoring, and already-sold product verification.

The system is implemented using React.js for the frontend, Node.js and Express.js for backend services, Solidity smart contracts for blockchain operations, and Ganache for local blockchain deployment. Experimental results demonstrate that the proposed system improves medicine traceability, enhances verification reliability, and provides better counterfeit detection compared to traditional QR-based verification systems.

Keywords: *Blockchain, Pharmaceutical Supply Chain, Counterfeit Detection, Drug Traceability, QR Verification, Smart Contracts, Ownership Tracking.*

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I. INTRODUCTION

The pharmaceutical industry plays a critical role in safeguarding public health by ensuring the availability of safe and effective medicines. However, the increasing circulation of counterfeit drugs has become a major challenge for healthcare systems worldwide. Counterfeit medicines may contain incorrect ingredients, improper dosages, or harmful substances, leading to severe health risks and financial losses. The complexity of modern pharmaceutical supply chains further increases the difficulty of tracking products and verifying their authenticity throughout the distribution process [1], [3].

To address this issue, several medicine verification solutions have been introduced based on centralized databases, barcode systems, and QR-code-enabled product authentication. These approaches allow stakeholders to retrieve product information and validate medicine records during distribution and sale. Although such methods improve visibility within the supply chain, they often rely on centralized management and limited verification mechanisms, making them vulnerable to data manipulation, unauthorized modifications, and replication attacks [2], [11].

Recent advancements in blockchain technology have created new opportunities for improving traceability and transparency in supply chain management. Blockchain maintains an immutable ledger of transactions, allowing participants to securely record product information and ownership changes without depending on a central authority. The integration of smart contracts further enables automated validation of transactions, secure record maintenance, and tamper-resistant tracking of

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pharmaceutical products across multiple stakeholders [6], [7], [10].

Several blockchain-enabled pharmaceutical tracking frameworks have been proposed in recent years to enhance medicine traceability and ownership management [1], [3], [4]. While these solutions successfully improve record integrity and decentralized verification, many of them primarily focus on storing medicine information and validating product existence within the blockchain network. As a result, products carrying duplicated QR codes may still appear legitimate if the copied identifier matches a valid blockchain record. This limitation creates opportunities for counterfeit products to infiltrate the supply chain despite the presence of blockchain-based verification mechanisms [2], [5].

Motivated by these challenges, this work presents a blockchain-enabled drug traceability framework that combines decentralized record management with intelligent counterfeit detection techniques. In addition to maintaining medicine ownership history and product verification records, the framework incorporates verification-log analysis, cloned-code identification, ownership validation, and suspicious activity monitoring to strengthen authenticity assessment. By integrating traceability management with behavioral verification mechanisms, the developed approach aims to improve pharmaceutical security, enhance stakeholder confidence, and reduce the circulation of counterfeit medicines within the supply chain.

II. LITERATURE SURVEY

The studies summarized in Table I demonstrate the growing adoption of blockchain technology for improving pharmaceutical traceability, transparency, and ownership management. Most existing approaches successfully enhance record integrity and supply-chain visibility through decentralized storage and smart-contract-based validation. However, a common limitation observed across these works is the reliance on product identifiers or QR codes as the primary means of authenticity verification. As a result, replicated QR codes and counterfeit products may still evade detection if the identifier corresponds to a valid record. In addition, limited attention has been given to verification-log analysis, suspicious activity monitoring, and behavioral counterfeit detection. These research gaps motivate the development of a more comprehensive framework that combines blockchain-enabled traceability with intelligent verification and anomaly-detection mechanisms.

Table 1 Literature Survey Table

Ref	Technique	Strength	Gap
[1]	Blockchain + QR	Traceability	No QR clone detection
[2]	Encrypted QR	Verification security	No ownership validation
[3]	Blockchain tracking	Scalability	No anomaly detection
[4]	Smart contracts	Secure records	Limited counterfeit analysis
[5]	NFT-based tracking	Unique identity	High Complexity

Recent research has additionally explored advanced blockchain security models using cryptographic verification and NFT-based medicine identity systems [4], [5]. Although these approaches improve medicine uniqueness and transaction security, they increase implementation complexity and still provide limited protection against physical QR duplication and suspicious verification behavior.

From the literature analysis, it is observed that most existing pharmaceutical traceability systems mainly focus on blockchain-based medicine storage, QR verification, and ownership management. However, many systems assume that a medicine is authentic if the QR code exists in the blockchain network. This creates vulnerabilities where counterfeiters can duplicate QR codes and reuse them on fake products. Existing research also provides limited support for suspicious scan analysis, repeated resale detection, and behavioral counterfeit monitoring.

The proposed system addresses these limitations by integrating duplicate QR detection, ownership validation, scan history monitoring, suspicious activity alerts, and sold-product verification into the blockchain-based pharmaceutical traceability process.

➢ *Problem Statement*

Counterfeit medicines continue to pose a significant threat to pharmaceutical supply chains despite the adoption of digital verification technologies. Existing medicine authentication solutions commonly rely on centralized databases, QR-code validation, or blockchain-based record storage to verify product authenticity. While these approaches improve traceability and transparency, many of them determine authenticity solely based on the presence of a valid medicine identifier within the system [1], [2].

This creates a critical security gap because counterfeiters can replicate QR codes from genuine products and apply them to unauthorized medicines. As a result, counterfeit products may successfully pass standard verification checks even when they do not originate from legitimate supply-chain participants. In addition, several existing solutions provide limited support for ownership validation, verification-log analysis, and detection of suspicious user activities [3], [4], [11].

Therefore, there is a need for a more comprehensive medicine verification framework that not only maintains secure traceability records but also evaluates verification behavior, ownership consistency, and potential indicators of counterfeit activity. Addressing these limitations can

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improve medicine authentication reliability and strengthen trust among pharmaceutical stakeholders.

➢ *Proposed System*

The developed framework aims to improve transparency, security, and reliability within pharmaceutical supply chains through the integration of blockchain technology and intelligent counterfeit detection techniques. Unlike conventional medicine authentication solutions that primarily validate the presence of a QR code, the presented approach evaluates ownership records, verification history, and behavioral indicators to strengthen authenticity assessment. This combination of decentralized traceability and verification intelligence enhances the ability to identify potentially counterfeit products.

The primary objective of this work is to address a major limitation observed in existing medicine verification solutions, where duplicated QR codes from genuine products can be reused on counterfeit medicines [1], [2]. In many currently available approaches, authenticity is determined by checking whether a product identifier exists within the database or blockchain ledger. Consequently, replicated QR labels may allow counterfeit products to pass standard verification procedures. To mitigate this issue, the developed framework combines blockchain-enabled traceability with verification-log analysis and counterfeit behaviour monitoring.

The framework is organized into four primary layers: frontend, backend, blockchain, and data management. These layers collectively support medicine onboarding, ownership management, product authentication, and counterfeit analysis. Manufacturers register medicine information including product identifiers, production details, and stakeholder information. Following validation, these records are securely maintained through Solidity smart contracts deployed on the blockchain network [7], [10].

Each registered medicine is assigned a unique QR code containing the medicine identifier used for product verification. The generated QR code is attached to the medicine package and later scanned using the QR verification module. The QR scanner extracts the medicine ID and sends verification requests to the backend server for blockchain validation.

The ownership transfer module plays an important role in maintaining pharmaceutical supply chain transparency. Medicines move through multiple stages including manufacturers, distributors, wholesalers, pharmacies, and customers. During each transfer process, ownership records are updated on the blockchain using secure smart contract transactions. This creates a complete immutable ownership history for every medicine stored within the blockchain network. By validating ownership chains, the system helps identify unauthorized medicine transfers and suspicious supply chain activities [11].

In addition to blockchain verification, the proposed system introduces intelligent counterfeit detection mechanisms to identify cloned QR codes and suspicious medicine verification behavior. Every QR verification attempt is logged with scan count, timestamp, and verification records. The system continuously analyzes scan activities to detect unusual behavior patterns that may indicate counterfeit distribution. Medicines are flagged as suspicious if repeated scans occur within short durations, if abnormal scan frequencies are detected, or if already-sold medicines are repeatedly verified.

The counterfeit detection module further improves medicine verification reliability by monitoring ownership inconsistencies and suspicious verification activities. If a medicine is scanned from unexpected supply chain stages or multiple verification attempts occur after product sale completion, the system generates counterfeit warning alerts. These intelligent monitoring techniques provide an additional layer of security beyond conventional blockchain verification methods.

The frontend of the system is developed using React.js to provide an interactive user interface for medicine registration, QR verification, ownership tracking, and counterfeit alerts. Backend services are implemented using Node.js and Express.js to handle API communication, blockchain interaction, and verification requests. Solidity smart contracts and Web3.js are used for blockchain operations and medicine data management, while Ganache is used as the local blockchain environment for development and testing. Scan history records and suspicious verification logs are maintained using database storage for efficient counterfeit analysis and monitoring.

By combining blockchain-based traceability with intelligent counterfeit detection mechanisms, the proposed system improves pharmaceutical supply chain security, enhances medicine authenticity verification, and provides a practical solution for reducing counterfeit medicine circulation.

Table 2 Technology Stack

Component	Technology Used
Frontend	React.js
Backend	Node.js
API Framework	Express.js
Blockchain	Ethereum
Smart Contracts	Solidity
Blockchain Interaction	Web3.js
Development Network	Ganache
QR Generation	QR Code Library

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QR Scanning	QR Scanner Library
Database	MongoDB

III. METHODOLOGY

The developed platform follows a blockchain-assisted pharmaceutical verification process combined with intelligent counterfeit detection mechanisms. The methodology is designed to provide secure medicine registration, ownership traceability, QR-based verification, and suspicious activity monitoring throughout the pharmaceutical supply chain. The overall workflow of the system includes medicine registration, blockchain storage, ownership transfer, QR generation, medicine verification, scan history logging, and counterfeit detection analysis.

Initially, manufacturers register medicines into the blockchain network using the medicine registration module. During registration, unique medicine information including medicine ID, medicine name, manufacturer details, and ownership information is entered into the system. The backend server processes the registration request and interacts with the blockchain smart contract through Web3.js. After successful validation, the medicine details are permanently stored on the blockchain network using Solidity smart contracts [7], [10].

Once the medicine is registered successfully, the system automatically generates a unique QR code associated with the medicine identifier. The generated QR code is attached to the medicine package and later used for verification by distributors, wholesalers, pharmacies, and customers. The QR code serves as the digital identity of the medicine throughout the supply chain process.

During medicine distribution, ownership transfer operations are performed between authorized supply chain participants. Ownership records are updated on the blockchain whenever medicines move between manufacturers, distributors, wholesalers, pharmacies, and customers. Every ownership transaction is validated through smart contracts and stored permanently in the blockchain ledger. This ownership chain creates transparent medicine traceability and helps identify unauthorized supply chain activities [11].

The medicine verification process begins when a user scans the QR code using the QR verification module. The QR scanner extracts the medicine identifier and sends a verification request to the backend server. The backend retrieves medicine information from the blockchain network and validates ownership details, medicine authenticity, and transaction history. If the medicine exists in the blockchain and ownership records are valid, the system displays the medicine as authentic.

In addition to standard blockchain verification, the proposed system performs intelligent counterfeit detection analysis using scan history monitoring and suspicious activity evaluation. Every verification attempt is recorded with scan count, timestamp, and verification status. The system continuously analyzes scan behavior to identify abnormal verification patterns that may indicate counterfeit medicine distribution.

The counterfeit detection module evaluates multiple suspicious conditions during verification. Medicines are flagged as suspicious if excessive scan attempts occur within short time intervals, if repeated verification requests are generated after medicine sale completion, or if ownership validation fails during supply chain tracing. The system also identifies possible QR duplication attacks when the same medicine is repeatedly scanned under unusual conditions [1], [2].

Whenever suspicious activities are detected, the system generates warning alerts to notify users about possible counterfeit risks. This additional verification layer improves medicine authenticity analysis beyond traditional QR-based blockchain systems. By integrating ownership validation, scan intelligence, and counterfeit behavior monitoring, the proposed methodology enhances pharmaceutical traceability and improves counterfeit detection reliability.

- *Medicine Registration Process*

Manufacturers register medicine details into the blockchain network using the medicine registration module. The backend validates the medicine information and stores the records securely using Solidity smart contracts. Each medicine is assigned a unique medicine ID for traceability purposes.

- *QR Code Generation and Verification*

After successful medicine registration, the system generates a QR code containing the medicine identifier. Users can scan the QR code using the QR scanner module to retrieve medicine details and verify authenticity using blockchain records. The verification process validates ownership details, medicine status, and transaction history before displaying the final result.

- *Ownership Transfer Process*

Ownership transfer transactions are performed whenever medicines move between manufacturers, distributors, wholesalers, pharmacies, and customers. Smart contracts securely update ownership records on the blockchain network to maintain transparent medicine traceability and prevent unauthorized supply chain modifications.

- *Counterfeit Detection Process*

The counterfeit detection process monitors scan history, ownership validation, repeated verification attempts, and suspicious scan activities. Medicines showing abnormal verification behavior such as duplicate scans, repeated resale attempts, or ownership inconsistencies are flagged with counterfeit warning alerts for further verification.

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➢ *Role-Based Dashboard Management*

The proposed system provides separate dashboards for different participants involved in the pharmaceutical supply chain to ensure secure and organized medicine management. Different user roles including manufacturers, distributors, wholesalers, pharmacies, and customers are provided with dedicated system functionalities based on their responsibilities within the supply chain.

The manufacturer dashboard allows medicine registration, QR code generation, ownership initialization, and medicine tracking operations. Manufacturers can add new medicines into the blockchain network and monitor product movement throughout the supply chain.

The distributor and wholesaler dashboards manage medicine transfer operations and ownership verification. These dashboards allow authorized participants to receive medicines, transfer ownership records, and verify medicine authenticity using blockchain data.

The pharmacy dashboard provides medicine verification, ownership confirmation, and medicine sale management functionalities. Pharmacies can verify incoming medicines before distribution to customers and update medicine status after successful sales.

The customer verification dashboard enables end users to scan QR codes and verify medicine authenticity using blockchain records. Customers can view medicine details, ownership history, verification status, and counterfeit warning alerts generated by the system.

The role-based dashboard structure improves supply chain transparency, enhances access control, and prevents unauthorized operations within the pharmaceutical verification system. By separating functionalities based on user responsibilities, the proposed system provides better security, usability, and management efficiency across the pharmaceutical supply chain.

➢ *System Workflow*

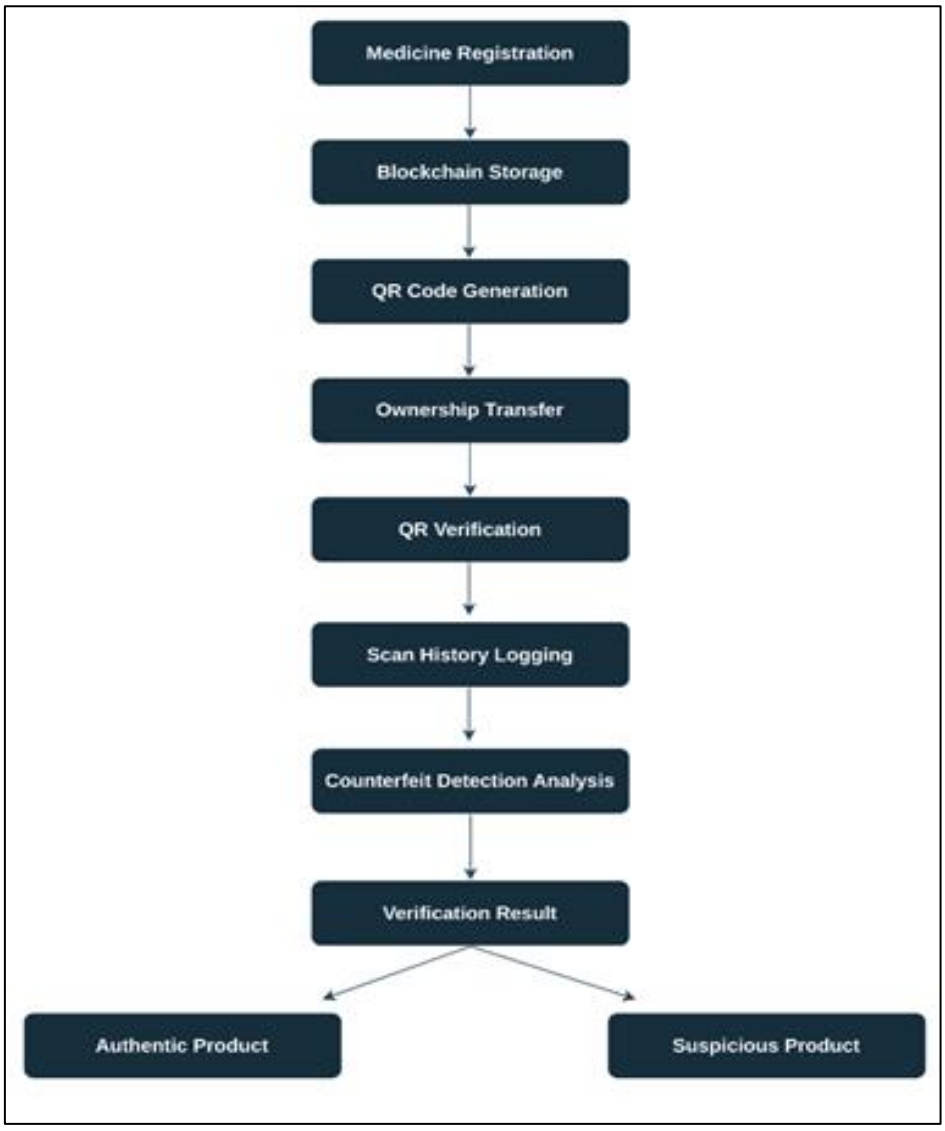

Fig 1 Workflow of the Proposed Blockchain-Based Drug Traceability and Intelligent Counterfeit Detection System

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IV. SYSTEM DESIGN

The proposed system follows a layered architecture that integrates frontend interfaces, backend services, blockchain operations, database storage, and intelligent counterfeit detection mechanisms. The architecture is designed to provide secure medicine traceability, transparent ownership management, QR-based verification, and suspicious activity monitoring across the pharmaceutical supply chain [1], [11].

The frontend layer is developed using React.js and provides separate dashboards for manufacturers, distributors, wholesalers, pharmacies, and customers. Each dashboard contains role-specific functionalities such as medicine registration, ownership transfer, medicine verification, QR scanning, and counterfeit alert monitoring. The frontend communicates with backend APIs to perform blockchain transactions and retrieve verification results.

The backend layer is implemented using Node.js and Express.js. It acts as the communication bridge between the frontend application, blockchain network, and database services. Backend APIs process medicine registration requests, ownership transfers, QR verification operations, scan history logging, and counterfeit detection analysis. Web3.js is used to interact with Solidity smart contracts deployed on the blockchain network [7], [10].

The blockchain layer stores critical medicine information including medicine IDs, ownership records, transfer history, and verification details. Solidity smart contracts manage medicine registration, ownership validation, and transaction integrity. Ganache is used as the local Ethereum blockchain environment during system development and testing. The decentralized nature of blockchain technology ensures immutability and prevents unauthorized modification of medicine records [6], [7].

The database layer stores scan history logs, suspicious verification activities, timestamps, scan counts, and counterfeit monitoring records. Storing scan analytics in the database instead of blockchain reduces blockchain storage overhead and improves system scalability. This hybrid storage approach improves verification efficiency while maintaining secure ownership records within the blockchain network.

The counterfeit detection layer continuously analyzes medicine verification activities to identify abnormal behavior patterns. This module monitors duplicate QR usage, repeated scan attempts, already-sold medicine verification, and ownership inconsistencies. If suspicious activities are detected, the system generates counterfeit warning alerts to notify users about potential risks. These intelligent monitoring techniques improve counterfeit identification beyond traditional QR verification systems [2], [4].

The integration of blockchain traceability, role-based dashboards, QR verification, and intelligent counterfeit analysis creates a secure and transparent pharmaceutical supply chain management system capable of improving medicine authenticity verification and reducing counterfeit medicine circulation.

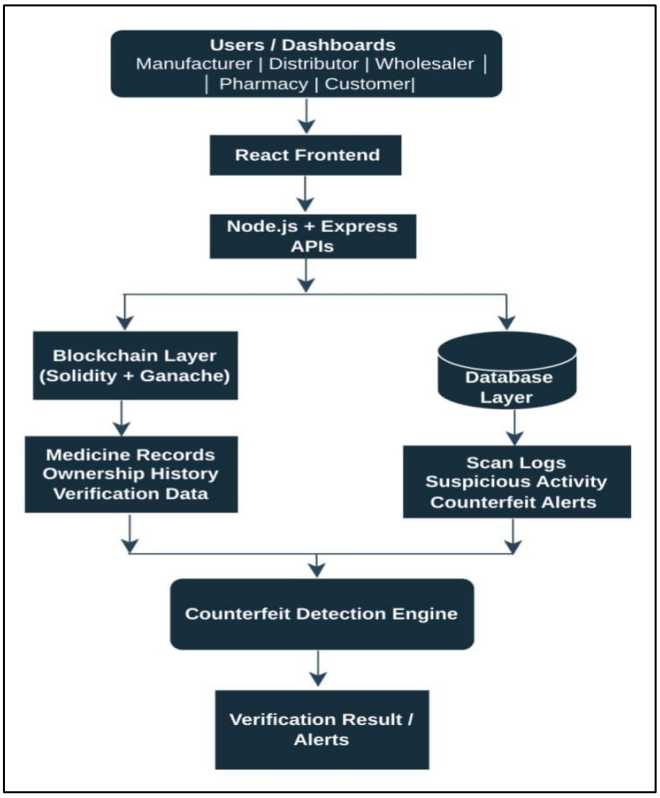

Fig 2 System Design of the Proposed Blockchain-Based Drug Traceability and Counterfeit Detection System

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The workflow of the proposed system begins with medicine registration performed by manufacturers through the registration dashboard. After successful registration, medicine details are securely stored on the blockchain network and a unique QR code is generated for each medicine. As the medicine moves through the pharmaceutical supply chain, ownership records are updated between distributors, wholesalers, pharmacies, and customers. During verification, users scan the QR code to retrieve medicine information from blockchain records. The system then performs ownership validation, scan history analysis, duplicate QR detection, and counterfeit behavior monitoring before displaying the final verification result. If suspicious activities are detected, counterfeit warning alerts are generated; otherwise, the medicine is marked as authentic.

V. IMPLEMENTATION AND RESULTS

The proposed Blockchain-Based Drug Traceability and Intelligent Counterfeit Detection System was successfully implemented and tested using a combination of blockchain technology, web technologies, QR verification mechanisms, and counterfeit detection modules. The implementation focuses on secure medicine registration, ownership traceability, QR-based medicine verification, and intelligent counterfeit analysis within the pharmaceutical supply chain.

The frontend interface was developed using React.js to provide role-based dashboards for manufacturers, distributors, wholesalers, pharmacies, and customers. Backend services were implemented using Node.js and Express.js to manage blockchain interaction, API communication, QR verification requests, and counterfeit detection analysis. Solidity smart contracts were deployed on the Ganache blockchain network using Web3.js for secure medicine data storage and ownership management.

The implemented system successfully performs medicine registration, QR code generation, medicine verification, ownership transfer tracking, scan history logging, and suspicious counterfeit detection. Experimental testing demonstrates that the system improves pharmaceutical traceability and enhances counterfeit medicine identification compared to traditional QR-based verification systems.

➢ *Medicine Registration Result*

The medicine registration module allows manufacturers to securely register medicine details into the blockchain network. After successful registration, the framework stores medicine information using Solidity smart contracts and generates a unique QR code associated with the medicine identifier. The generated QR code is later used for medicine verification throughout the supply chain.

The registration process ensures that product records remain tamper-resistant and can be accessed for future authentication. This mechanism establishes the foundation for secure traceability by linking each medicine package with its corresponding blockchain record.

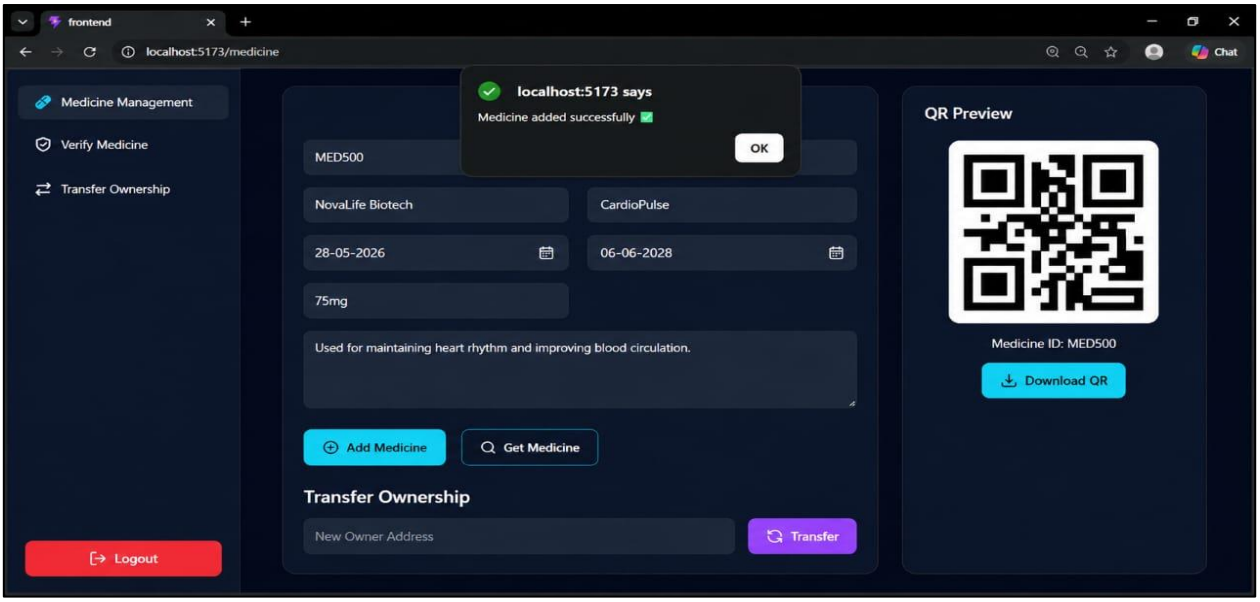

Fig 3 Medicine Registration and QR Code Generation Interface

➢ *QR Verification Result*

Figure 4 presents the medicine verification interface of the developed framework. Users can authenticate a medicine by entering the medicine ID or scanning the QR code attached to the package. Upon verification, the application retrieves blockchain records and displays details such as medicine name, verification status, current owner, and scan count.

The interface also provides ownership history and a supply-chain timeline, enabling users to trace product movement from the manufacturer to the end customer. By combining blockchain-based validation with traceability information, the verification module improves transparency and assists in identifying potentially counterfeit products.

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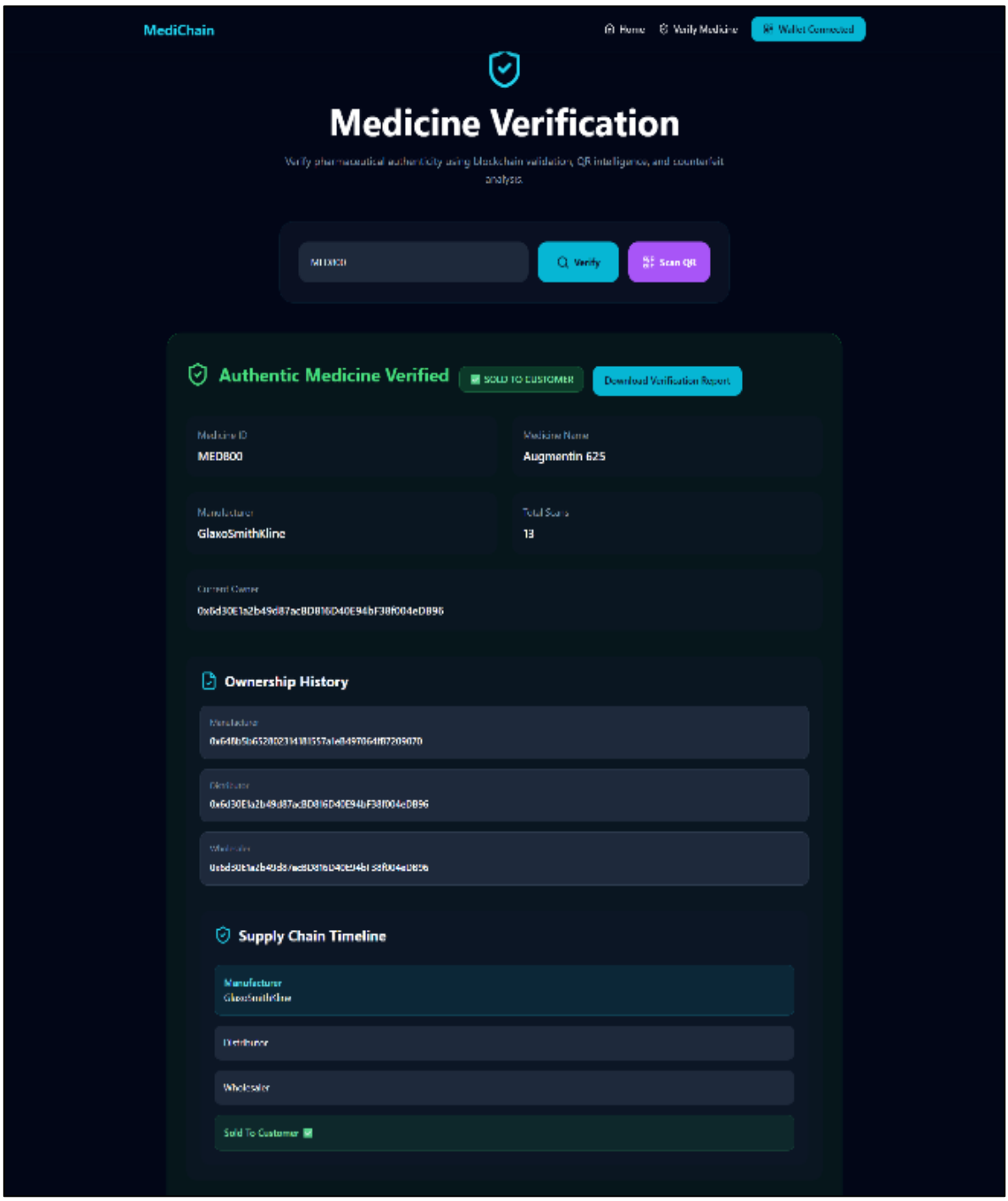

Fig 4 QR-Based Medicine Verification Process

➢ *Ownership Transfer Result*

The ownership transfer module records medicine movement between manufacturers, distributors, wholesalers, pharmacies, and customers. Each ownership transaction is securely stored on the blockchain network, creating transparent and immutable medicine traceability records across the pharmaceutical supply chain.

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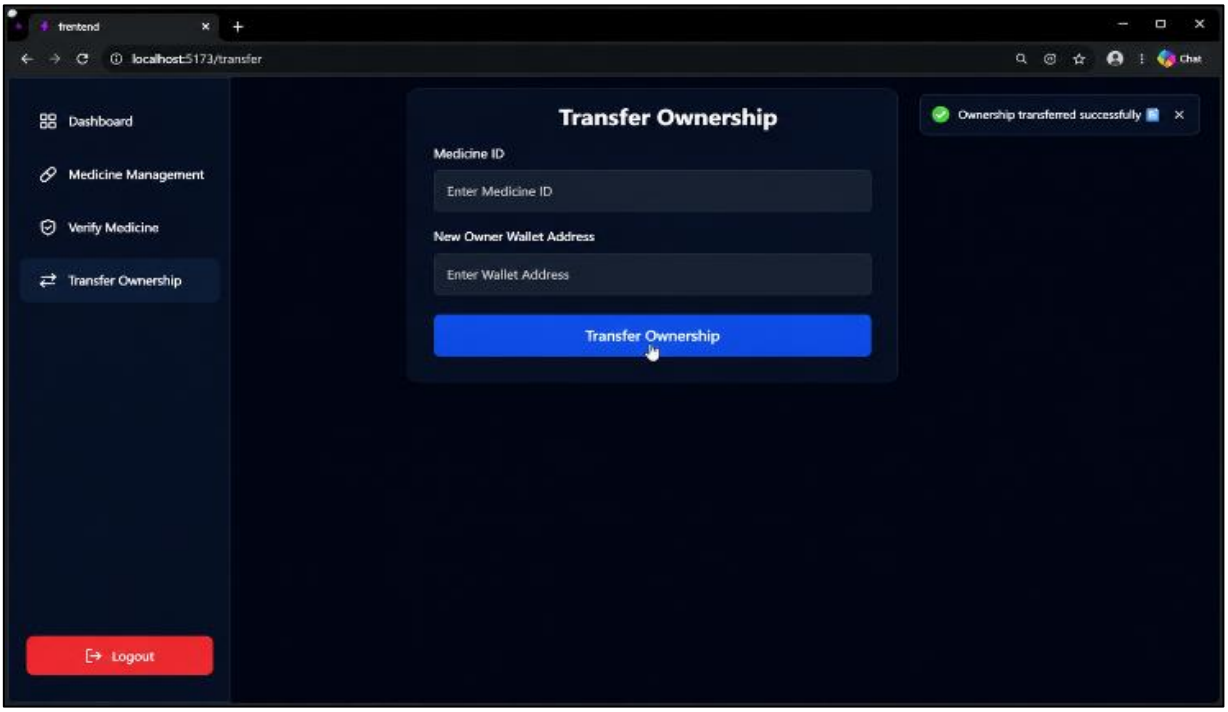

Fig 5 Blockchain-Based Ownership Transfer and Traceability

➢ *Counterfeit Detection Result*

The counterfeit detection module analyzes medicine verification behavior to identify suspicious activities related to counterfeit products. The system successfully detects duplicate QR verification attempts, repeated scans, ownership inconsistencies, and already-sold medicine verification requests. Suspicious medicines are flagged with counterfeit warning alerts for users.

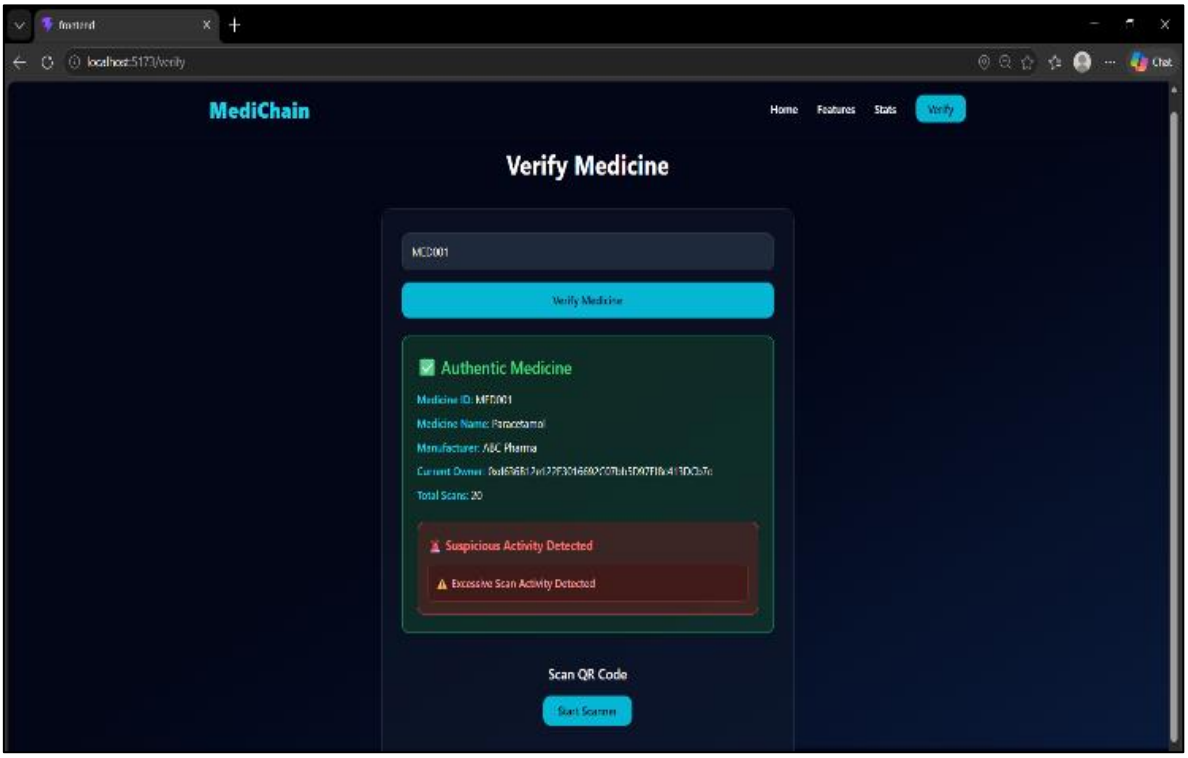

Fig 6 Suspicious Counterfeit Detection and Warning Alert

➢ *Scan History Monitoring Result*

Figure 6 illustrates the scan history monitoring and analytics dashboard. The line graph displays weekly scan activity, where the x-axis represents the days of the week and the y-axis indicates the number of medicine verification scans performed. This visualization helps identify verification trends and unusual spikes in scan activity.

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The pie chart shows the distribution of product safety status, highlighting the proportion of authentic and suspicious products detected during verification. The dashboard also presents key statistics such as total medicines registered, total verification scans, suspicious products identified, and recent counterfeit alerts. These analytics assist in monitoring verification behavior and support the identification of potential counterfeit activities.

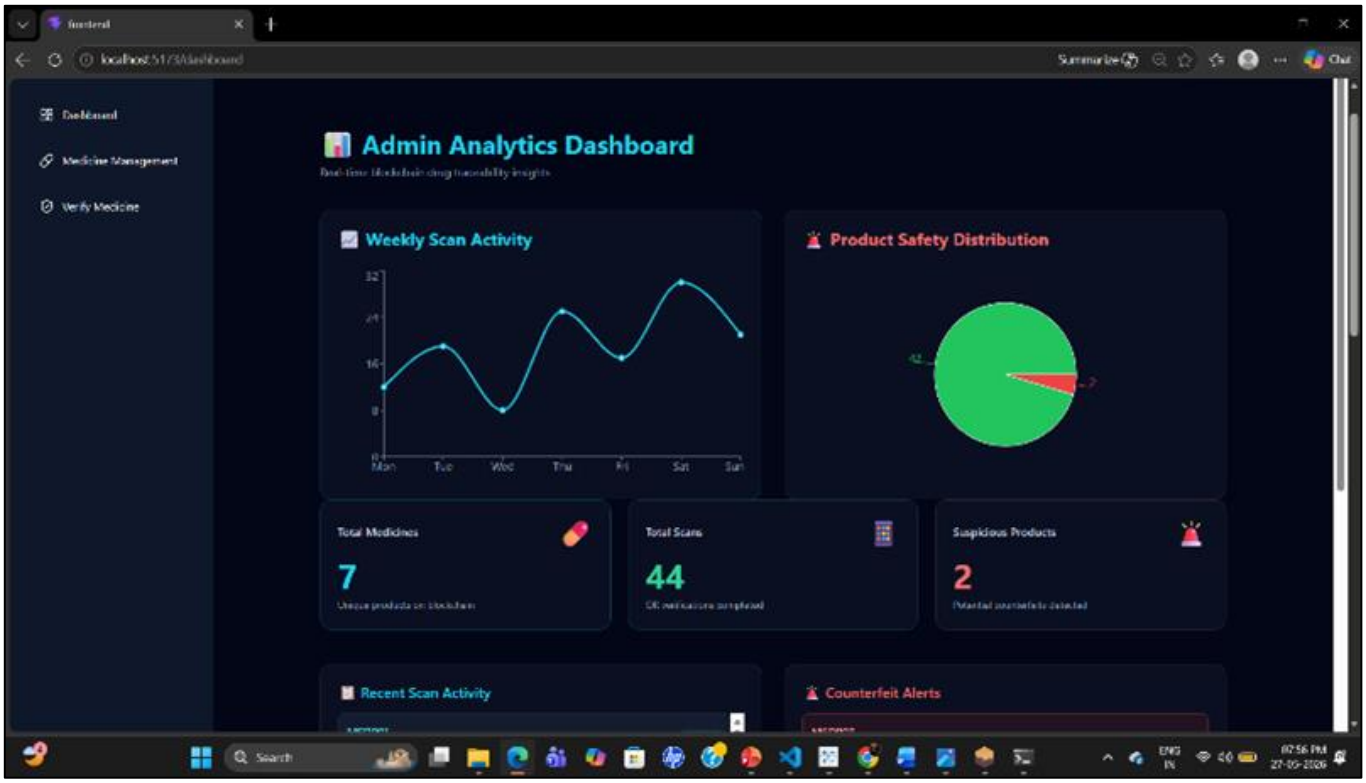

Fig 7 Medicine Scan History and Verification Analytics

Table 3 Feature Comparison Table

Feature	Traditional QR System	Existing blockchain systems	Proposed System
QR Verification	QR code validation	Blockchain record validation	Multi-layer authentication and behavioral analysis
Data Integrity	Vulnerable to modification	Tamper-resistant	Tamper-resistent
Product Traceability	Basic	End-to-end tracking	End-to-end tracking with ownership validation
QR Clone Resistance	Vulnerable to duplication	Limited protection	Verification-log analysis and clone detection
Ownership Validation	Not supported	Supported	Enhanced through traceability auditing
Counterfeit Identification	Identifier-based	Record-based	Behavior-based and record-based
Verification Analytics	Not available	Limited	Scan-history and anomaly analysis
Already-Sold Product Detection	No	No	Yes
Supply Chain Visibility	Low	Moderate	High
Decision Support	Basic Verification	Product Authentication	Authentication risk alertswith

VI. ADVANTAGES OF THE PROPOSED SYSTEM

The proposed Blockchain-Based Drug Traceability and Intelligent Counterfeit Detection System provides several advantages over traditional pharmaceutical verification systems. The integration of blockchain technology with intelligent counterfeit detection mechanisms improves medicine traceability, supply chain transparency, and verification reliability [1], [11].

The decentralized nature of blockchain technology prevents unauthorized modification of medicine records and ensures secure ownership management across the pharmaceutical supply chain. Smart contracts automate medicine registration and ownership transfer operations,

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reducing dependency on centralized systems and improving transaction integrity [6], [7], [10].

The proposed system enhances counterfeit prevention by introducing duplicate QR detection, suspicious scan monitoring, ownership validation, and already-sold medicine verification mechanisms. Unlike traditional systems that only verify QR existence, the proposed approach performs behavioral verification analysis to identify possible counterfeit activities. This improves the accuracy of medicine authenticity verification and strengthens pharmaceutical security [2], [4].

The role-based dashboard structure improves access control and allows different supply chain participants including manufacturers, distributors, wholesalers, pharmacies, and customers to securely manage medicines according to their responsibilities. The QR-based verification system also provides quick and user-friendly medicine authentication for customers and supply chain participants.

In addition, the hybrid architecture using blockchain and database storage improves scalability by storing critical ownership records on blockchain while maintaining scan history and analytics data within the database layer. This reduces blockchain storage overhead and improves overall system efficiency [3], [11].

The proposed system further improves transparency within the pharmaceutical supply chain by maintaining immutable ownership history and secure transaction records. The integration of intelligent counterfeit detection mechanisms with blockchain traceability provides a practical and scalable approach for reducing counterfeit medicine circulation and improving medicine verification reliability.

VII. LIMITATIONS OF THE SYSTEM

Although the proposed system improves pharmaceutical traceability and counterfeit detection, certain limitations still exist. The system currently uses a local Ganache blockchain environment for development and testing purposes, which limits large-scale real-world deployment capabilities. Deployment on public blockchain networks may introduce additional challenges related to transaction cost, scalability, and network latency [6], [7].

The proposed system mainly relies on QR-based medicine verification, and physical QR labels can still be copied, damaged, or tampered with under certain conditions. While suspicious scan monitoring helps identify duplicate QR usage, complete prevention of physical counterfeit replication remains challenging. Existing QR-based verification approaches also face similar limitations in real-world pharmaceutical environments [1], [2].

The accuracy of suspicious activity analysis depends on scan history availability, verification frequency, and user participation. Limited scan activity may reduce the effectiveness of counterfeit behavior analysis and duplicate detection mechanisms. In addition, continuous internet connectivity is required for real-time blockchain verification and ownership validation.

The system currently focuses on software-level counterfeit detection and does not integrate hardware-based security technologies such as NFC or IoT-enabled tracking devices. Public blockchain deployment, large-scale pharmaceutical integration, and cross-organizational interoperability are also outside the current implementation scope [3], [11].

Despite these limitations, the proposed system provides an effective and practical approach for improving pharmaceutical traceability and counterfeit medicine detection using blockchain-assisted verification and intelligent monitoring techniques.

VIII. FUTURE ENHANCEMENTS

Several advanced features can be integrated into the proposed system in future developments to further improve pharmaceutical security and counterfeit detection capabilities. Machine learning and artificial intelligence techniques can be incorporated to perform advanced counterfeit prediction, anomaly detection, and suspicious behavior analysis based on medicine verification patterns and scan history records [9].

The system can also be integrated with public blockchain platforms to support large-scale decentralized pharmaceutical supply chain management. Public blockchain deployment may improve transparency and enable secure medicine verification across multiple organizations and healthcare networks. In addition, IPFS-based decentralized storage can be incorporated to improve scalability and reduce blockchain storage overhead [8].

Future enhancements may also include mobile application support, geo-location-based counterfeit analysis, real-time supply chain analytics, and government pharmaceutical monitoring integration. Geo-location monitoring can help identify abnormal medicine verification activities across different regions and strengthen counterfeit detection reliability.

Hardware-based verification mechanisms such as NFC-enabled medicine packaging and IoT-assisted supply chain monitoring may further improve medicine authenticity verification in large-scale healthcare environments [12]. Additional role-based access control mechanisms and automated pharmaceutical auditing features can also be integrated to improve security and regulatory compliance.

The integration of advanced analytics, decentralized storage technologies, and intelligent monitoring mechanisms can further enhance the efficiency, scalability, and reliability of blockchain-based pharmaceutical traceability systems in future healthcare applications.

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IX. CONCLUSION

Counterfeit medicines continue to create major challenges in pharmaceutical supply chains by affecting patient safety, medicine authenticity, and healthcare reliability. Traditional medicine verification systems mainly rely on centralized databases and static QR verification methods, which remain vulnerable to QR duplication attacks and counterfeit product replication.

This paper proposed a Blockchain-Based Drug Traceability and Intelligent Counterfeit Detection System that combines blockchain technology with software-level counterfeit detection mechanisms to improve pharmaceutical supply chain security and transparency. The proposed system integrates medicine registration, blockchain-based ownership tracking, QR verification, scan history monitoring, duplicate QR detection, suspicious activity analysis, and sold-product verification to provide reliable medicine authenticity verification.

The implementation results demonstrate that the proposed system successfully improves medicine traceability and enhances counterfeit detection compared to conventional QR-based verification approaches. By integrating intelligent verification analysis with blockchain traceability, the system provides a practical and scalable solution for reducing counterfeit medicine circulation within pharmaceutical supply chains.

The proposed work highlights the importance of combining blockchain security with intelligent behavioral analysis for effective counterfeit prevention in real-world healthcare environments.

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