Review Article

Blockchain and Artificial Intelligence in the Pharmaceutical Industry: Enhancing Drug Supply Chain Security and Healthcare Applications

Ramanan M, Rukmangathan Palani, Sangavi G, Senthilnathan D N, Praveena S, Kalaikumar S, Jeevitha Moorthy

From, Department of Pharmaceutics, Shri Venkateshwara College of Pharmacy, Ariyur, Puducherry - 605102.

ABSTRACT

Background: The pharmaceutical industry faces major challenges related to counterfeit medicines, lack of supply chain transparency, inefficient data management, and fragmented healthcare information systems. Counterfeit drugs pose serious risks to patient safety and compromise the integrity of pharmaceutical distribution networks. Emerging digital technologies such as blockchain and artificial intelligence (AI) have gained increasing attention as potential solutions for improving security, traceability, and transparency in pharmaceutical and healthcare systems. **Objective:** This review aims to examine the role of blockchain technology and its integration with artificial intelligence in strengthening pharmaceutical supply chain security and enhancing healthcare data management. **Methods:** A literature review was conducted using peer-reviewed publications from 2017 to September 2023. The Scopus database was primarily used to identify relevant studies addressing blockchain applications in pharmaceutical supply chains, healthcare systems, and AI-driven technologies. A total of 353 publications were initially identified, and approximately 121 relevant articles were selected for detailed analysis. **Results:** The review indicates that blockchain technology provides a decentralized and immutable framework for recording and verifying transactions across pharmaceutical supply chains. Blockchain-based systems enable improved drug serialization, product authentication, and real-time traceability, which can help prevent counterfeit medicines from entering the market. In healthcare, blockchain facilitates secure management of electronic health records, supports clinical trial transparency, and enables reliable patient monitoring. The integration of blockchain with artificial intelligence and Internet of Things (IoT) technologies further enhances data analysis, predictive monitoring, and healthcare decision-making. **Conclusion:** Blockchain technology has significant potential to improve transparency, security, and efficiency in pharmaceutical supply chains and healthcare systems. Although challenges such as scalability, regulatory issues, and system interoperability remain, continued technological development and collaborative efforts may enable broader adoption of blockchain-enabled healthcare ecosystems.

Key words: Blockchain Technology, Pharmaceutical Supply Chain, Artificial Intelligence in Healthcare, Drug Traceability, Counterfeit Drug Detection, Healthcare Data Security.

Blockchain is a distributed ledger technology introduced by Satoshi Nakamoto in 2008 as the foundational infrastructure for Bitcoin [1]. It enables secure, tamper-resistant data recording by organizing transactions into cryptographically linked blocks validated through consensus mechanisms, eliminating reliance on centralized authorities [2]. In healthcare and pharmaceutical contexts, permissioned blockchain systems allow controlled access to sensitive data while maintaining data integrity and privacy [3]. The pharmaceutical industry is one of the largest and fastest-growing sectors globally. Recent estimates indicate that the global pharmaceutical market reached approximately USD 1.81 trillion in 2025 and is projected to grow to USD 3.12 trillion by 2032, reflecting a compound annual growth rate exceeding 8% [4]. Similarly, global medicine spending is expected to surpass USD 1.6–1.9 trillion in the coming years, driven by increasing demand for innovative therapies and expanding healthcare access [5,6]. Healthcare expenditure has also risen significantly, reaching nearly USD 9.8 trillion worldwide, representing approximately 10% of global GDP [7].

Within OECD countries, pharmaceutical spending constitutes a substantial portion of healthcare costs, with prescription medicines accounting for a major share of total expenditure [8]. These trends highlight the growing economic burden on healthcare systems and the urgent need for efficient, transparent, and secure pharmaceutical supply chains. Despite this growth, the pharmaceutical sector faces critical

Access this article online

Quick Response Code

Received – 26th March 2026
Initial Review – 27th March 2026
Accepted – 09th April 2026

Correspondence to: Dr. M. Jeevitha, Department of Pharmaceutics, Shri Venkateshwara College of Pharmacy, Ariyur, Puducherry - 605102.

Email: jeevipharma@gmail.com

challenges, particularly the proliferation of counterfeit and substandard medicines. According to the World Health Organization, approximately 1 in 10 medical products in low- and middle-income countries are falsified or substandard, with prevalence rates exceeding 30% in some regions [9]. The global counterfeit pharmaceutical market is estimated to generate between USD 65 billion and USD 200 billion annually [10]. More broadly, counterfeit goods account for approximately USD 467 billion in global trade, representing about 2.3% of total imports worldwide [11].

These counterfeit medicines pose serious risks to patient safety, undermine trust in healthcare systems, and result in substantial economic losses. To address these challenges, emerging digital technologies such as blockchain and artificial intelligence (AI) are being increasingly explored. Blockchain enhances supply chain transparency, traceability, and data integrity, while AI enables advanced data analytics, predictive modeling, and decision support. The integration of these technologies offers a synergistic approach to improving pharmaceutical supply chain security and healthcare data management.

METHODOLOGY

This study is a narrative literature review aimed at synthesizing existing research on the application of blockchain technology and its integration with artificial intelligence in pharmaceutical supply chains and healthcare systems. A comprehensive literature search was conducted using the Scopus database to identify relevant studies published between January 2017 and September 2023. The search strategy included keyword combinations such as “blockchain AND pharmaceutical supply chain,” “blockchain AND healthcare,” “blockchain AND drug traceability,” “artificial intelligence AND blockchain healthcare,” and “blockchain AND clinical trials,” with Boolean operators (AND, OR) applied to refine the results. Studies were selected based on their relevance to the research topic, focusing on peer-reviewed journal articles and conference papers published in English that addressed blockchain applications in pharmaceutical or healthcare contexts, including AI integration.

Non-English publications, editorials, commentaries, and studies not directly related to the research scope were excluded. The selection process involved screening titles and abstracts followed by full-text evaluation to ensure relevance and quality. A total of 353 records were initially identified, of which 121 articles were considered relevant and included in the final analysis.

The study was guided by the following research questions:

RQ1: What is the current state of research in blockchain and AI integration?

RQ2: Which industries benefit most from combining blockchain and artificial intelligence?

RQ3: How can blockchain and AI technologies be effectively integrated?

RQ4: What challenges arise when integrating these technologies? [11]

Blockchain Architecture for Pharmaceutical Systems

To improve transparency and efficiency within pharmaceutical supply chains, blockchain-based architectures have been proposed. These systems can enhance product recall procedures and reduce the time required to identify defective pharmaceutical products.

Product recalls typically involve multiple decision-making processes and corrective actions, including Corrective and Preventive Action (CAPA) procedures. Several stakeholders are involved in these processes, including manufacturers, regulatory authorities, and consumers.

The proposed blockchain architecture integrates four primary data sources to enable efficient and secure pharmaceutical supply chain management. These include Centralized Database Management Systems (CDMS), which store structured data in traditional centralized repositories; Distributed Database Management Systems (DDMS), which allow data sharing across multiple interconnected nodes; and Blockchain Database Management Systems (BDMS), which provide a decentralized, immutable ledger for secure transaction recording. In addition, real-time data collection systems, such as Internet of Things (IoT) devices, sensors, RFID tags, and QR codes, continuously capture and transmit supply chain information. The integration of these data sources ensures comprehensive data visibility, enhances traceability, and supports reliable decision-making across pharmaceutical supply networks [12].

Data collected from these devices are transmitted to a smart gateway that processes and harmonizes the raw information before transferring it to the blockchain network. The perception layer collects environmental and product data, which are then processed by the Component Based on Smart Contract (CBSC) module.

The blockchain network layer contains technologies such as cryptographic security mechanisms, decentralized applications (DApps), and consensus protocols [13]. Smart contracts allow data to be transferred securely from supply chain participants to the blockchain ledger.

The consensus mechanism ensures that all network participants agree on the validity of recorded transactions. Unlike centralized systems, decentralized applications operate across distributed networks, ensuring transparency and preventing data modification.

The application layer includes enterprise systems such as Supply Chain Management Systems (SCMS), Logistics Management Systems (LMS), Enterprise Resource Planning (ERP) software, and quality monitoring systems such as Out-of-Specification (OOS) and Out-of-Trend (OOT) monitoring systems [14-17].

Enforcement of Anti-Counterfeiting Measures

Distributed ledger technology offers significant potential for improving anti-counterfeiting initiatives in the pharmaceutical industry. Blockchain traceability systems allow regulatory authorities and customs agencies to verify the authenticity of pharmaceutical products more effectively.

Brand owners can register security features of legitimate pharmaceutical products within blockchain networks. Customs authorities can then verify these features using scanning technologies when inspecting shipments. Technologies implemented under regulatory frameworks such as the Falsified Medicines Directive (FMD) and the Drug Supply Chain Security Act (DSCSA) allow rapid verification of pharmaceutical products at multiple supply chain checkpoints [2].

Blockchain systems also allow consumers to verify product authenticity using digital identifiers such as QR codes. As online pharmaceutical sales continue to increase, such verification systems are becoming increasingly important for protecting patients from counterfeit drugs.

Serialization in Pharmaceutical Supply Chains

To prevent counterfeit drugs from entering legitimate pharmaceutical distribution channels, regulatory authorities have introduced strict serialization requirements. For example, the European Union Directive 2011/62/EU requires pharmaceutical manufacturers to implement safety features that allow product verification throughout the supply chain. Serialization involves assigning a unique identification code to each pharmaceutical package. This unique identifier enables supply chain participants to track the product from manufacturing to distribution [18-20].

During the packaging process, pharmaceutical products are assigned unique codes that comply with regulatory standards specific to each country. Enterprise Resource Planning (ERP) systems coordinate the packaging process and ensure that identification codes are correctly applied.

Vision inspection systems verify that identifiers are printed correctly on packaging materials. These systems record the number of units within each shipment and generate a hierarchical matrix list containing packaging information. During batch release, serialization data are transmitted to regulatory authorities and stored within serialization software databases for long-term traceability.

Blockchain Enhancement

Blockchain technology enhances serialization systems by providing a decentralized and tamper-resistant ledger for storing pharmaceutical product data. Unlike traditional centralized systems, blockchain networks maintain shared records accessible to authorized participants.

Several technology companies have developed enterprise blockchain platforms for supply chain applications, including IBM Watson, SAP Leonardo, and DNV-GL solutions [21,22]. Smart contracts represent one of the most promising applications of blockchain technology. These automated digital agreements allow stakeholders to conduct transactions without intermediaries [23,24].

In pharmaceutical supply chains, serialization data can be encrypted and stored on blockchain networks. This ensures that product traceability information remains secure and permanently accessible to supply chain participants.

Applications of Blockchain Technology in Healthcare and Pharmaceutical Systems

Blockchain technology has attracted significant attention in healthcare and pharmaceutical research due to its ability to provide secure, transparent, and tamper-resistant data management. Several practical applications of blockchain have been proposed to address challenges related to data security, interoperability, patient monitoring, and clinical research. The following sections highlight key applications of blockchain technology in healthcare and pharmaceutical systems.

1. Sequential Management of Patient Data

During clinical investigations and routine healthcare processes, a large amount of patient-related data is generated. This includes diagnostic reports, medical examinations, laboratory test results, treatment records, and health assessments. Managing such data securely while maintaining accessibility for authorized users is a major challenge.

Blockchain technology can be used to record patient data sequentially in a distributed ledger, ensuring that all medical information remains immutable and verifiable. Healthcare professionals can confirm the authenticity of stored data by comparing the blockchain records with original documentation. Blockchain also integrates with existing security frameworks such as cryptographic data-sharing mechanisms, ensuring secure access to patient information.

During the patient registration process, healthcare providers record information such as personal identification, date of birth, diagnosis, treatment history, and mobility records in electronic medical systems. Traditionally, this data is stored in centralized databases or cloud systems; however, blockchain-based solutions provide improved security and integrity for managing such records [25–28].

2. Evaluation of Medical Treatment Outcomes

Blockchain technology can support pharmaceutical companies and healthcare providers in collecting and analyzing real-time health data. Through decentralized data platforms, medical information can be securely recorded and shared among authorized stakeholders.

Drug manufacturers may use blockchain-enabled digital platforms to collect patient feedback and treatment outcomes directly. This allows pharmacists and healthcare professionals to guide patients more effectively regarding medication usage and treatment adherence.

Furthermore, sensor-based monitoring systems integrated with blockchain can provide real-time alerts to healthcare providers when abnormalities occur. This enables faster clinical responses and improved patient care. Reliable and verified clinical data can also assist researchers in evaluating treatment effectiveness across larger patient populations, leading to more accurate conclusions regarding therapeutic outcomes [29–32].

3. Data Validation and Integrity

In blockchain-based healthcare systems, every transaction or data entry is automatically validated through distributed consensus mechanisms. Once data are verified, encrypted, and stored on the blockchain, they cannot be altered without network consensus.

This capability ensures the integrity and reliability of medical information stored in the system. Pharmaceutical companies, research institutions, and healthcare providers are increasingly exploring blockchain-based solutions to enhance data reliability and transparency in clinical and operational processes. As a result, blockchain technology has the potential to significantly improve trust in healthcare data management systems [33–37].

4. Accountability and Data Security

Blockchain technology enhances accountability within healthcare ecosystems by providing transparent and traceable records of all data transactions. Healthcare professionals can access verified patient data without compromising privacy, allowing them to focus more on clinical care.

Secure data sharing between healthcare providers, research organizations, and pharmaceutical companies can facilitate improved diagnosis, treatment planning, and clinical research. Additionally, blockchain-based systems can support studies on rare diseases by enabling secure and efficient collaboration among global healthcare institutions.

By enabling secure and decentralized data exchange, blockchain platforms help healthcare organizations maintain transparency while preserving patient confidentiality and data integrity [38–41].

5. Management of Medical Records

One of the most promising applications of blockchain in healthcare is the management of electronic health records (EHRs). Blockchain systems can be used to store, transmit, and manage patient medical records across multiple healthcare providers.

Patients can upload their medical data to blockchain networks through secure applications, allowing healthcare providers to access comprehensive medical histories when needed. Smart contracts integrated into blockchain systems also enable interaction between medical sensors, monitoring devices, and healthcare databases.

Currently, patient medical records are often fragmented across multiple healthcare institutions. Blockchain technology can integrate these records into a unified system while maintaining patient control over data access. This integrated approach allows physicians to obtain a more comprehensive understanding of patient health conditions and improve treatment decisions while ensuring data authenticity and privacy protection [42–46].

6. Clinical Trial Management

Blockchain technology can address several challenges associated with clinical trials, including data fragmentation, data manipulation, and lack of transparency. By storing clinical trial data on a decentralized ledger, blockchain ensures that all research records remain tamper-resistant and verifiable.

Researchers can record experimental procedures, study protocols, and results on the blockchain to ensure transparency and credibility. This approach reduces the risk of selective reporting or manipulation of clinical trial outcomes.

Additionally, blockchain can support pharmaceutical supply chain monitoring during clinical trials by tracking drug distribution from manufacturers to research participants. Such capabilities enhance the reliability of clinical research and improve trust among stakeholders involved in medical studies [47–50].

7. Detection of Fraudulent Information

Blockchain technology improves transparency in healthcare data management and helps detect fraudulent activities. In clinical research, blockchain can ensure that research protocols, experimental procedures, and results remain publicly verifiable.

Smart contracts can be used to automatically enforce research guidelines and regulatory requirements during clinical trials. This ensures that research activities follow predefined standards and that all recorded information remains accurate and trustworthy.

Furthermore, blockchain-based platforms allow patients and regulatory authorities to monitor clinical research

activities more effectively. By providing secure access to medical data, blockchain systems empower patients to maintain greater control over their health information [51–55].

8. Reduction of Administrative Costs

Blockchain technology can significantly reduce administrative overhead in healthcare systems by eliminating redundant processes and intermediaries involved in data verification and record management.

Traditional healthcare systems often rely on multiple intermediaries to manage and validate medical records. Blockchain enables direct and secure data exchange between authorized participants, reducing operational complexity and associated costs.

Healthcare providers can access summarized patient medical histories directly from the blockchain network, allowing faster diagnosis and treatment planning. In addition, blockchain can address issues such as medical record theft, data inconsistencies, and system failures, ultimately improving overall healthcare efficiency [56–59].

9. Patient Monitoring

Blockchain-based healthcare systems can support real-time patient monitoring through integration with Internet of Things (IoT) devices and medical sensors. These technologies enable healthcare providers to remotely monitor patient health conditions and respond quickly to medical emergencies.

Blockchain networks ensure the integrity of collected data while improving supply chain transparency for medical equipment and pharmaceuticals. Additionally, blockchain platforms can facilitate secure digital identity verification for healthcare providers and institutions.

Through improved monitoring of healthcare resources such as hospital beds, medical supplies, and environmental conditions, blockchain systems can enhance the efficiency and responsiveness of healthcare delivery systems [60–63].

10. Support for Research Collaboration

Blockchain technology can provide a reliable and transparent infrastructure for medical research collaboration. Researchers can securely share anonymized patient data across institutions without compromising patient privacy.

By facilitating secure data exchange, blockchain encourages collaborative research initiatives that can accelerate scientific discovery and innovation in healthcare. A broader exchange of clinical findings can lead to improved treatment strategies and stronger partnerships between researchers and healthcare organizations.

Blockchain systems may also support patient referral management by securely recording treatment plans and healthcare interactions within distributed ledgers [64–67].

11. Enhanced Security in Pharmaceutical Systems

Blockchain technology improves security across pharmaceutical supply chains by ensuring drug provenance and authenticity. Secure blockchain records help prevent counterfeit pharmaceutical products from entering the healthcare system.

Through improved interoperability and secure data sharing, healthcare professionals can access accurate medical information to support diagnosis and treatment decisions. Blockchain also enables centralized yet secure storage of healthcare data while maintaining decentralized verification mechanisms.

By strengthening pharmaceutical supply chain transparency, blockchain technology ultimately contributes to improved patient safety and trust in healthcare systems [68–72].

12. Reduction in Data Transmission Time and Cost

Blockchain-based networks can reduce the time and cost associated with data transmission across healthcare systems. Distributed ledger technology enables efficient verification of healthcare credentials and secure transfer of patient information.

Blockchain also ensures confidentiality and protection of patient records through cryptographic mechanisms. These capabilities enable healthcare organizations to develop secure data-sharing networks that are both cost-effective and reliable.

In blockchain systems, every transaction is recorded with a timestamp and validated by multiple nodes in the network. This distributed approach ensures the authenticity of stored information while facilitating faster and more efficient healthcare data management [73–77].

LIMITATIONS

This narrative review has several limitations. The literature search was limited to the Scopus database, which may have excluded relevant studies from other sources such as PubMed and Web of Science. Most included studies are conceptual or pilot-based, with limited real-world clinical validation of blockchain and artificial intelligence applications. In addition, heterogeneity in study designs, technologies, and application areas limits direct comparison and generalizability. Furthermore, the rapid evolution of blockchain and AI may render some findings outdated. Future research should focus on large-scale implementation, standardized frameworks, and empirical validation.

CONCLUSION

Blockchain technology represents a powerful digital innovation capable of transforming pharmaceutical supply chains and healthcare systems. Its decentralized architecture provides enhanced transparency, security, and traceability for

pharmaceutical product distribution. By enabling secure data sharing among stakeholders, blockchain systems can significantly reduce the risk of counterfeit medicines entering global markets. Integration with artificial intelligence and IoT technologies further enhances the potential of blockchain applications by enabling real-time monitoring, predictive analysis, and automated verification of healthcare data.

Although blockchain technology offers numerous benefits, challenges such as scalability limitations, regulatory concerns, and system interoperability must be addressed before large-scale implementation becomes feasible. Future research should focus on developing scalable blockchain architectures, improving integration with emerging digital technologies, and establishing regulatory frameworks that support secure and efficient blockchain adoption within healthcare environments. Overall, blockchain technology has the potential to significantly improve pharmaceutical supply chain security, enhance healthcare data management, and contribute to safer and more efficient healthcare systems worldwide.

REFERENCE

1. Abbas K, Afaq M, Ahmed Khan T, Song WC. A blockchain and machine learning-based drug supply chain management and recommendation system for smart pharmaceutical industry. Electronics. 2020;9(5):852.
2. Clark B, Burstall R. Blockchain, IP and the pharma industry—how distributed ledger technologies can help secure the pharma supply chain. J Intellect Prop Law Pract. 2018;13(7):531–3.
3. Gaynor M, Gillespie K, Roe A, Crannage E, Tuttle-Newhall JE. Blockchain applications in the pharmaceutical industry. Blockchain Healthc Today. 2024;7(1).
4. Pharmaceutical market poised for growth, expected to hit USD 3.12 trillion by 2032. BioSpace [Internet]. 2025. Available from: https://www.biospace.com/
5. Shrivastava G. Pharmaceutical market size and YoY growth rate, 2026–2033 [Internet]. Coherent Market Insights; 2026 [cited 2026 Apr 8]. Available from: https://www.coherentmarketinsights.com/
6. Global medicine spending set to reach $US1.6 trillion by 2025. Pharmacoecon Outcomes News. 2021;878(1):12–2.
7. World Health Organization. Global spending on health: coping with the pandemic. Geneva: WHO; 2024.
8. OECD. Health at a glance 2025: OECD indicators. Paris: OECD; 2025.
9. World Health Organization. Substandard and falsified medical products [Internet]. 2024 [cited 2026 Apr 9]. Available from: http://who.int/news-room/fact-sheets/detail/substandard-and-falsified-medical-products
10. Pathak R, Gaur V, Sankrityayan H, Gogtay J. Tackling counterfeit drugs: the challenges and possibilities. 2023;37:1–10.
11. Ziavrou KS, Noguera S, Boumba VA. Trends in counterfeit drugs and pharmaceuticals before and during COVID-19 pandemic. Forensic Sci Int. 2022;338:111382.
12. Bahrudin SSM, Illyas MI, Desa MI. Tracking and tracing technology for halal product integrity over the supply chain. In: Proc Int Conf Electr Eng Inform. 2011.
13. Castro M, Druschel P, Kermarrec AM, Rowstron AIT. Scribe: a large-scale and decentralized application-level multicast infrastructure. IEEE J Sel Areas Commun. 2002;20(8):1489–99.
14. Kuselman I, Pennecchi F, Burns C, Fajgelj A, de Zorzi P. Investigating out-of-specification test results of chemical composition based on metrological concepts. Accredit Qual Assur. 2009;15(5):283–8.
15. Yu B, Zeng L, Ren P, Yang H. A unified framework for detecting out-of-trend results in stability studies. Stat Biopharm Res. 2018;10(4):237–43.
16. Sarkis L. Strategic analysis of logistics and supply chain management systems using the analytical network process. Transp Res E. 1998;34(3):201–15.
17. Stenger AJ. Information systems in logistics management: past, present, and future. Transp J. 1986;26(1):65–82.
18. Smith G, Smith J, Brindley D. The falsified medicines directive: how to secure your supply chain. J Generic Med. 2014;11(3–4):169–72.
19. Whyte J. Pharmaceutical serialization: an implementation guide. 2017.
20. Mettler M. Blockchain technology in healthcare: the revolution starts here. In: Proc IEEE Healthcom. 2016. p.1–3.
21. Buterin V. A next generation smart contract & decentralized application platform. 2014.
22. Huckle S, Bhattacharya R, White M, Beloff N. Internet of things, blockchain and shared economy applications. Procedia Comput Sci. 2016;98:461–6.
23. Christidis K, Devetsikiotis M. Blockchains and smart contracts for the internet of things. 2016.
24. Chiacchio F, D'Urso D, Compagno L, Chiarenza M, Velardita L. Towards a blockchain-based traceability process: a case study from pharma industry. In: IFIP Adv Inf Commun Technol. 2019. p.451–7.
25. Ejaz M, Kumar T, Kovacevic I, Ylianttila M, Harjula E. Health-BlockEdge: blockchain-edge framework for reliable low-latency digital healthcare applications. Sensors. 2021;21(7):2502.
26. De Aguiar EJ, Faiçal BS, Krishnamachari B, Ueyama J. A survey of blockchain-based strategies for healthcare. ACM Comput Surv. 2020;53(2):1–27.
27. Aggarwal S, Kumar N, Alhussein M, Muhammad G. Blockchain-based UAV path planning for healthcare 4.0. IEEE Netw. 2021;35(1):20–9.
28. Mackey TK, Kuo TT, Gummadi B, et al. "Fit-for-purpose?" challenges and opportunities for blockchain in healthcare. BMC Med. 2019;17(1).
29. Khatoon A. A blockchain-based smart contract system for healthcare management. Electronics. 2020;9(1):94.
30. Abu-Elezz I, Hassan A, Nazeemudeen A, Househ M, Abd-Alrazaq A. Benefits and threats of blockchain technology in healthcare. Int J Med Inform. 2020;142:104246.
31. Vaishya R, Javaid M, Khan IH, Vaish A, Iyengar KP. Significant role of modern technologies for COVID-19 pandemic. J Ind Integr Manag. 2021.
32. Hussien HM, Yasin SM, Udzir NI, Ninggal MIH, Salman S. Blockchain technology in healthcare industry. J Ind Inf Integr. 2021;22:100217.
33. Deol G. Custodial violence in Kashmir by Indian security forces. Int J Crim Justice Sci. 2018;13(2):110.
34. Onik MMH, Aich S, Yang J, Kim CS, Kim HC. Blockchain in healthcare: challenges and solutions. In: Big Data Analytics for Intelligent Healthcare Management. 2019. p.197–226.
35. Agbo CC, Mahmoud QH, Eklund JM. Blockchain technology in healthcare: a systematic review. Healthcare. 2019;7(2):56.
36. Engelhardt MA. Hitching healthcare to the chain. Technol Innov Manag Rev. 2017;7(10):22–34.
37. Tanwar S, Parekh K, Evans R. Blockchain-based electronic healthcare record system. J Inf Secur Appl. 2020;50:102407.
38. Wang S, Wang J, Wang X, et al. Blockchain-powered parallel healthcare systems. IEEE Trans Comput Soc Syst. 2018;5(4):942–50.
39. Jiang S, Cao J, Wu H, Yang Y, Ma M, He J. BlocHIE: a blockchain-based platform for healthcare information exchange. In: Proc IEEE SMARTCOMP. 2018.
40. Zhang P, Walker MA, White J, Schmidt DC, Lenz G. Metrics for assessing blockchain healthcare apps. In: Proc IEEE HealthCom.

41. Hathaliya J, Sharma P, Tanwar S, Gupta R. Blockchain-based remote patient monitoring. In: Proc IEEE IACC. 2019.
42. Berdik D, Otoum S, Schmidt N, Porter D, Jararweh Y. Survey on blockchain for information systems. Inf Process Manag. 2021;58(1):102397.
43. Du X, Chen B, Ma M, Zhang Y. Application of blockchain in smart healthcare. J Healthc Eng. 2021;2021:1–13.
44. Haleem A, Javaid M, Singh RP, Suman R, Rab S. Blockchain applications in healthcare. Int J Intell Netw. 2021;2:130–9.
45. Celesti A, Ruggeri A, Fazio M, Galletta A, Villari M, Romano A. Blockchain-based healthcare workflow. Sensors. 2020;20(9):2590.
46. Zhang P, Kamel Boulos MN. Blockchain solutions for healthcare. In: Precision Medicine. 2020. p.519–24.
47. Gökalp E, Gökalp MO, Çoban S, Eren PE. Opportunities and challenges of blockchain in healthcare. In: Inf Syst Conf. 2018.
48. Leeming G, Cunningham J, Ainsworth J. A ledger of me. Front Med. 2019;6.
49. Javaid M, Haleem A. Industry 4.0 applications in medical field. Curr Med Res Pract. 2019;9(3).
50. Bhattacharya P, Tanwar S, Bodke U, Tyagi S, Kumar N. BinDaaS: blockchain deep-learning service. IEEE Trans Netw Sci Eng. 2020;8(2).
51. Omar AA, Bhuiyan MZA, Basu A, Kiyomoto S, Rahman MS. Privacy-friendly blockchain healthcare platform. Future Gener Comput Syst. 2019;95:511–21.
52. Agbo CC, Mahmoud QH. Comparison of blockchain frameworks. Internet Technol Lett. 2019;2(5):e122.
53. Sun Y, Zhang R, Wang X, Gao K, Liu L. Attribute-based signature for healthcare blockchain. In: Proc IEEE ICCCN. 2018.
54. Zheng K, Liu Y, Dai C, Duan Y, Huang X. Model checking PBFT consensus mechanism. In: Proc ITME. 2018.
55. Pham HL, Tran TH, Nakashima Y. Secure remote healthcare system using blockchain. In: Proc IEEE Globecom Workshops. 2018.
56. Kasyapa MSB, Vanmathi C. Blockchain integration in healthcare. Front Digit Health. 2024;6.
57. Ismail L, Materwala H, Zeadally S. Lightweight blockchain for healthcare. IEEE Access. 2019;7:149935–51.
58. Chidubem C. Blockchain in healthcare: opportunities and challenges. Int J Healthc Inf Syst Inform. 2020;15(3):82–97.
59. Curbera F, Dias DM, Simonyan V, Yoon WA, Casella A. Blockchain for healthcare transformation. IBM J Res Dev. 2019;63(2–3):8:1–8:9.
60. Srivastava G, Crichigno J, Dhar S. Secure healthcare blockchain for IoT devices. In: Proc IEEE CCECE. 2019.
61. Ray PP, Dash D, Salah K, Kumar N. Blockchain for IoT-based healthcare. IEEE Syst J. 2020;15(1).
62. Mamoshina P, Ojomoko L, Yanovich Y, et al. Blockchain and AI in biomedical research. Oncotarget. 2017;9(5).
63. Munoz DJ, Constantinescu DA, Asenjo R, Fuentes L. ClinicAppChain blockchain solution. In: Adv Intell Syst Comput. 2019.
64. Soltanisehat L, Alizadeh R, Hao H, Choo KKR. Challenges in blockchain healthcare systems. IEEE Trans Eng Manag. 2020.
65. Cyran MA. Blockchain as a foundation for healthcare data sharing. Blockchain Healthc Today. 2018.
66. Chen HS, Jarrell JT, Carpenter KA, Cohen DS, Huang X. Patient-centered blockchain healthcare model. Biomed J Sci Tech Res. 2019;20(3):15017–22.
67. Mazlan AA, Mohd Daud S, Mohd Sam S, Abas H, Abdul Rasid SZ, Yusof MF. Scalability challenges in healthcare blockchain. IEEE Access. 2020;8:23663–73.
68. Vaishya R, Haleem A, Vaish A, Javaid M. Emerging technologies to combat COVID-19. J Clin Exp Hepatol. 2020;10(4):409–11.
69. Nguyen DC, Pathirana PN, Ding M, Seneviratne A. BEdgeHealth architecture. IEEE Internet Things J. 2021.
70. Islam A, Young Shin S. Blockchain-based secure healthcare with UAV. Comput Electr Eng. 2020;84:106627.
71. Dhagarra D, Goswami M, Sarma PRS, Choudhury A. Big data and blockchain healthcare model. Bus Process Manag J. 2019.
72. Islam N, Faheem Y, Din IU, Talha M, Guizani M, Khalil M. Blockchain-based fog computing healthcare. Future Gener Comput Syst. 2019;100:569–78.
73. Angraal S, Krumholz HM, Schulz WL. Blockchain technology. Circulation. 2017;10(9).
74. Saha A, Amin R, Kunal S, Vollala S, Dwivedi SK. Blockchain healthcare systems review. Secur Priv. 2019.
75. Pandey P, Litoriya R. Blockchain healthcare services challenges. Health Policy Technol. 2020;9(1).
76. Koshechkin KA, Klimenko GS, Ryabkov IV, Kozhin PB. Blockchain in public healthcare Russia. Procedia Comput Sci. 2018;126:1323–8.
77. Kumar VN, Hassan MM, Pant R, Hima Bindu V, Sivasankar G. IoT and smart materials in manufacturing. E3S Web Conf. 2024;564:07007.

How to cite this article: Ramanan M, Palani R, Sangavi G, Senthilnathan D N, Praveena S, Kalaikumar S, Moorthy J. Blockchain and Artificial Intelligence in the Pharmaceutical Industry: Enhancing Drug Supply Chain Security and Healthcare Applications. Indian J Pharm Drug Studies. 2026; Online First.

Funding: None; *Conflicts of Interest: None Stated*