

Review Article

Bridging the Gaps: AI Algorithms and Blockchain Implementation in Digital Technologies for Tuberculosis Management under NTEP

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DOI: <https://doi.org/10.24321/2278.2044.202605>

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How to cite this article:

Danasekaran R, Yenuganti V V. Bridging the Gaps: AI Algorithms and Blockchain Implementation in Digital Technologies for Tuberculosis Management under NTEP. Chettinad Health City Med J. 2026;15(1):23-27.

Date of Submission: 2025-09-24

Date of Acceptance: 2026-04-03

A B S T R A C T

To enhance tuberculosis (TB) management, India's National Tuberculosis Elimination Program (NTEP) makes use of digital technologies such as the Nikshay app and 99DOTS. The initiative still has a lot of obstacles to overcome, including low infrastructure, improper data management, and lack of digital literacy among patients and healthcare workers. This article is a narrative review synthesising existing literature on the integration of artificial intelligence and blockchain technologies in tuberculosis management under NTEP. Blockchain and artificial intelligence (AI) have the potential to revolutionise TB care under NTEP by improving treatment adherence prediction, data security, and transparency.

Keywords: Tuberculosis, Ntep, Artificial Intelligence, Blockchain, Digital Technologies, Nikshay

Introduction

Tuberculosis (TB) remains a major public health concern in India, accounting for approximately 25% of the global TB burden, making it the highest contributor worldwide according to the latest WHO Global Tuberculosis Report 2025.¹ Despite significant progress, including a 21% decline in TB incidence between 2015 and 2024, India continues to face substantial challenges in achieving TB elimination targets.^{1,2}

A few studies conducted across India have reported on the four main obstacles with the present digital tools utilised in NTEP, which include digital illiteracy, data management issues, poor digital infrastructure, and lack of bug reporting.^{3,4} The research has highlighted missing

records, duplicate entries, and fragmented data entry across systems such as Nikshay and 99DOTS.³ As a result of these inefficiencies, treatments are often skipped or delayed.⁵ Mobile-based solutions remain difficult for many TB patients to use, especially in rural regions, leading to increased reliance on healthcare workers for reminders and adherence tracking.^{6,7} In rural areas, unstable internet connectivity and outdated hardware further limit the effective use of digital tools.⁴ Patients and healthcare professionals worry about the confidentiality and security of patient information as well as the openness of financial transactions pertaining to incentive payments. The incorporation of blockchain and AI into NTEP's digital infrastructure provides several strategic advantages to tackle these issues.

Chettinad Health City Medical Journal (P-ISSN: 2277-8845 & E-ISSN: 2278-2044)

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AI Integration in ICT tools used in NTEP

AI can perform complex computational tasks and rapidly analyse large volumes of patient data within NTEP. Artificial intelligence holds significant promise in transforming tuberculosis management through improved diagnosis, treatment adherence, and monitoring. By leveraging large datasets, AI algorithms can identify patterns and trends that may not be apparent to human analysts, enabling earlier detection and more personalised care.^{6,8} However, organisations remain cautious in adopting AI in healthcare, particularly in areas that directly impact patient outcomes, due to concerns regarding reliability, safety, and ethical implications.⁹ Nonetheless, AI can substantially enhance TB control when integrated into the NTEP framework, even in resource-limited settings with poor internet connectivity and low-end hardware. The following are key applications of AI within NTEP.

Several studies and pilot implementations highlight the practical utility of digital technologies in TB care. The 99DOTS platform has demonstrated improved treatment adherence through low-cost mobile-based monitoring, especially in resource-limited settings.^{5,7} Similarly, the Nikshay platform has enabled real-time tracking of TB patients and improved notification rates under NTEP [5, 10].

AI-based tools have shown promising results in TB diagnosis, particularly in automated chest X-ray interpretation, improving sensitivity and reducing diagnostic delays in high-burden settings.^{11,12} Additionally, predictive analytics models have been used to identify patients at risk of treatment default, allowing targeted interventions.¹³

Blockchain-based healthcare models, such as the proposed NikshayChain, have demonstrated potential in ensuring secure and transparent TB data management, particularly for financial incentive tracking and interdepartmental data sharing.^{14,15} These pilot concepts suggest that integration of AI and blockchain can significantly strengthen TB programme implementation.¹⁶

- **E-learning tools using AI:** Artificial intelligence is increasingly being used to replicate the role of a human tutor by adapting learning methods and prioritising content based on the learner's capacity, preferences, and knowledge gaps. The development of effective e-learning materials requires ensuring that content is relevant, accurate, up-to-date, visually engaging, and appropriately formatted for the intended delivery medium.¹⁷ While addressing digital illiteracy remains a significant challenge, there is concern that the introduction of AI could potentially widen the gap in technological understanding among TB patients and grassroots healthcare workers. However, AI-driven systems can also be tailored to match the user's level

of digital literacy, thereby improving accessibility and usability. This approach, however, has not been extensively field-tested in TB programme settings, and definitive conclusions cannot yet be drawn.

- **Drug adherence:** Using information from treatment history, demographics, and behavioural patterns, AI systems can be utilised to predict patient adherence tendencies. This enables early identification of high-risk patients and allows timely interventions, thereby reducing treatment dropout rates and improving overall outcomes.¹³ Acting as a personalised support system, AI can create a customised environment for tuberculosis patients by assisting them in adhering to medication regimens and promoting healthier behaviours. Additionally, AI can provide automated reminders and feedback that can be communicated to healthcare providers for improved monitoring and follow-up.^{6,7}
- **Automation in data entry:** By automating repetitive tasks such as data entry and appointment reminders, AI can significantly reduce the workload on healthcare workers (HCWs). In low-connectivity settings, AI-enabled systems can support offline data storage with synchronisation once internet access becomes available, ensuring continuity of care in resource-limited environments. This facilitates uninterrupted patient monitoring and improves efficiency in programme implementation. [18] Additionally, AI can be applied to analyse disaggregated patient data to identify individuals with clinical features suggestive of tuberculosis, disease relapse, or adverse drug reactions, thereby strengthening surveillance and follow-up mechanisms.⁸
- **AI in aiding diagnosis:** In TB programme administration, "connected diagnostics" is emerging as a key concept that enables remote monitoring of diagnostic devices and centralised data consolidation. Artificial neural networks have been applied in challenging clinical scenarios such as sputum smear-negative TB and pleural TB, where conventional diagnostic tools are limited. Despite these advancements, such cases continue to pose diagnostic challenges for clinicians.⁸ Over time, the role of computer-assisted radiology has evolved significantly, and automated detection of tuberculosis on digital chest radiographs is now demonstrating strong clinical utility and practical relevance.^{11,12}
- **Telemedicine:** Potential AI applications have increased in tandem with the advent of telemedicine, or the virtual diagnosis of physicians. AI might make it possible for them to provide remote patient care by tracking their information through detectors.¹⁸
- **Predictive algorithms in Treatment & Drug discovery:** In addition to the above applications, AI can help identify

predictors of treatment failure, thereby contributing to improved patient management and outcomes. Furthermore, AI has significant potential in tuberculosis drug development, including applications in chemical synthesis, drug design, screening, polypharmacology, and drug repurposing, which can accelerate the discovery of effective therapeutic agents.¹⁹

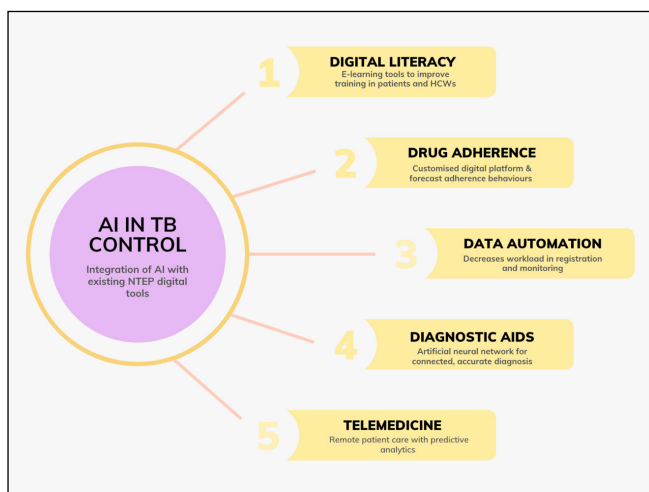


Figure 1. AI usage in digital tools under NTEP

Block chain in digital ecosystem of NTEP

Within NTEP, healthcare workers often face delays due to multi-step approval processes, multiple levels of data verification, repetitive administrative tasks, and the need to maintain physical documentation at various stages. These challenges can hinder timely delivery of healthcare services. From the patient's perspective, lack of data ownership and limited transparency in sharing personal information with government programmes reduce trust in the system. Blockchain technology offers a solution by enabling secure, decentralised, and tamper-proof data storage.²⁰ It functions as a distributed ledger in which data are stored in interconnected "blocks", such as patient records or medical transactions, forming a continuous "chain". This structure ensures high data integrity and security, as information, once recorded, is difficult to alter or delete.^{21,22}

Blockchain can be integrated into the existing NTEP digital ecosystem by linking it with platforms such as Nikshay through application programming interfaces (APIs). A hybrid architecture can be adopted where the following are true

- Patient data continues to be entered in Nikshay
- Blockchain acts as a secure backend ledger for validation and audit trails
- Smart contracts automate incentive disbursement under Nikshay Poshan Yojana

- AI modules operate on anonymised datasets for predictive analytics

This layered integration ensures minimal disruption to existing workflows while enhancing transparency, security, and efficiency.

There are numerous ways to make use of this NTEP technology, like:

- **Data security:** Blockchain can be used to manage financial transactions, including those related to treatment incentives, and to store patient records in a decentralised, tamper-proof ledger. This approach addresses concerns raised by patients and healthcare workers by ensuring data integrity, enhancing security, and promoting accountability within the system.^{21, 22} NTEP can reduce the risk of fraud or misreporting by tracking every stage of patient care, from diagnosis to treatment, on a decentralised ledger. This helps ensure that resources are distributed fairly and utilised effectively.
- **Transparency:** Drug supply chain transparency is a critical component of NTEP, where delays in drug delivery can have serious consequences. Blockchain-based systems such as MediLedger enable verification of drug authenticity, tracking of supply chains, and validation of expiration details, thereby improving accountability and reducing the risk of counterfeit medications.²³
- **Health records:** Electronic Health Records (EHRs) related to tuberculosis are often maintained across multiple healthcare institutions, leading to fragmented data and limited accessibility to patient history. Blockchain-based healthcare architectures have been developed to facilitate secure, interoperable, and patient-centric data sharing across stakeholders, thereby improving continuity of care.²²
- **Monitoring of cases:** Advances in digital health technologies, including remote monitoring systems, allow continuous tracking of patient health status through sensors and connected devices. When integrated with AI and secure data systems, these tools enhance patient visibility for healthcare providers and support proactive and preventive care strategies.^{18,24}
- **Smart contracts in drug adherence:** Smart contracts are self-executing digital protocols in which predefined conditions are automatically enforced without the need for intermediaries. In TB care, smart contracts can update patient records and notify healthcare providers when medication adherence is confirmed through digital tools. Additionally, they can be used to automate incentive disbursement upon successful completion of treatment, thereby promoting adherence and programme efficiency.^{14,22}

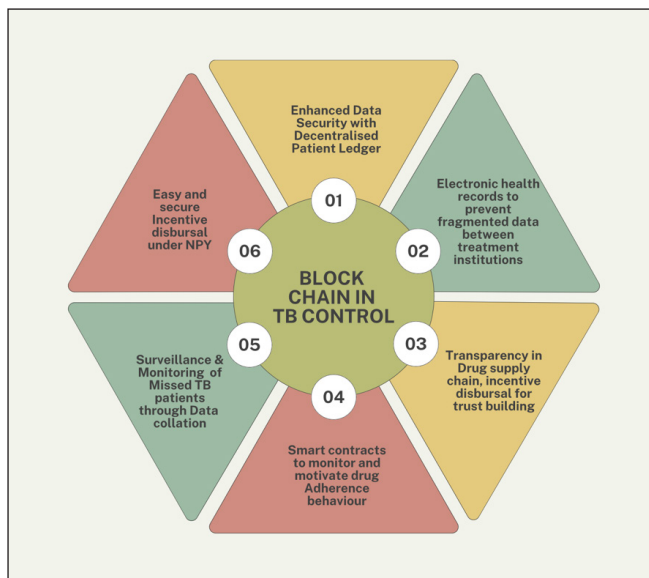


Figure 2. Block chain technology advantages in digital tools under NTEP

Payment/Incentive disbursement: Blockchain technology offers significant potential for improving schemes such as the Nikshay Poshan Yojana (NPY), where financial data must be securely managed across multiple departments. The proposed NikshayChain framework enables secure sharing of tuberculosis patient data with appropriate access controls, facilitating coordination among stakeholders.¹⁴ Through the use of smart contracts, incentive disbursement can be automated by verifying predefined conditions such as unique patient and Nikshay IDs, bank details, Aadhaar information, and duration of treatment. This ensures timely, transparent, and error-free transfer of benefits to eligible beneficiaries.^{14,22}

Synergistic approach of AI and blockchain

The integration of blockchain technology with artificial intelligence (AI) can create a secure, decentralised, and efficient system for managing sensitive healthcare data. Blockchain provides a transparent and immutable platform for data storage, while AI enables advanced data analysis and decision-making. Together, these technologies can enhance treatment monitoring, improve predictive analytics, and strengthen programme implementation under NTEP.¹⁶

Conceptual Framework for AI–Blockchain Integration in NTEP

A conceptual model for integrating AI and blockchain in TB programme management involves three layers:

Data Layer:

Collection of patient data through Nikshay, 99DOTS, and diagnostic tools

Blockchain Layer:

Secure storage, validation, and sharing of data across stakeholders

AI Layer:

Data analysis for prediction of treatment adherence, diagnosis support, and risk stratification

Application Layer:

Decision-making support for healthcare workers, automated alerts, and policy-level insights

This integrated framework enables a closed-loop system ensuring data integrity, real-time monitoring, and evidence-based decision-making.

Discussion

The integration of AI and blockchain into TB control programmes presents significant opportunities but also raises important considerations. While AI enhances predictive capabilities and diagnostic accuracy, its effectiveness depends heavily on data quality and infrastructure availability.^{8,9} Similarly, blockchain improves transparency and security but requires substantial initial investment and technical expertise.^{15,20}

In the Indian context, feasibility remains a key concern due to disparities in digital infrastructure, especially in rural areas.^{4,10} Cost implications, including system development, training, and maintenance, must be carefully evaluated before large-scale implementation.²⁰

Ethical concerns such as data privacy, informed consent, and algorithmic bias must also be addressed. The use of sensitive patient data necessitates robust governance frameworks to ensure confidentiality and compliance with data protection regulations.^{21,22}

Additionally, interoperability between existing systems and new technologies remains a challenge. Without proper integration strategies, fragmentation of digital health systems may increase rather than decrease.^{3,20}

Therefore, phased implementation through pilot studies, along with policy support and stakeholder engagement, is essential for successful adoption.^{7,16}

Conclusion

The integration of artificial intelligence and blockchain into NTEP represents a transformative approach to addressing persistent challenges in TB management. While AI enhances predictive analytics and clinical decision-making, blockchain ensures secure, transparent, and accountable data management. However, successful implementation requires addressing challenges related

to infrastructure, cost, ethics, and system interoperability. Future research should prioritise pilot testing and real-world validation to assess scalability and impact. Adoption of these technologies, if implemented strategically, can significantly contribute to achieving India's goal of TB elimination.

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