

Strengthening Pharmaceutical Supply Chain Integrity in India: a Review of Drug Authentication, Traceability and Risk Mitigation

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ABSTRACT

Pharmaceutical supply chain integrity is essential for ensuring medicine authenticity, patient safety, and effective regulatory oversight in India. Increasing distribution complexity, unauthorized pharmaceutical movement, and inconsistent monitoring practices create significant challenges for maintaining product quality and traceability. This narrative review examines pharmaceutical supply chain vulnerabilities, drug authentication technologies, and risk mitigation strategies within the Indian pharmaceutical sector. Drawing on existing academic literature and regulatory perspectives, the study evaluates therapeutic-category risks, distribution-stage weaknesses, drug diversion mechanisms, and emerging technological interventions. The review identifies serialization, QR-code verification, blockchain-based traceability, and digital monitoring as potential approaches for improving product identification and supply chain transparency. However, technological adoption remains constrained by implementation costs, fragmented information systems, limited interoperability, and regulatory coordination challenges. The analysis highlights the importance of integrating digital authentication with supplier verification, inventory monitoring, regulatory compliance, and stakeholder collaboration. The study concludes that strengthening pharmaceutical supply chain integrity requires a coordinated framework combining technological innovation, organizational accountability, and effective regulatory governance. These approaches may contribute to reducing distribution vulnerabilities, improving medicine traceability, and supporting a more secure and resilient pharmaceutical supply chain in India.

Keywords: Pharmaceutical supply chain integrity, Drug authentication, Medicine traceability, Serialization, Risk mitigation, India

1. INTRODUCTION

The pharmaceutical industry represents one of the most important components of the global healthcare system, contributing significantly to disease prevention, medical treatment, public health protection, and economic development. The availability of safe, effective, and quality-assured medicines depends not only on pharmaceutical manufacturing standards but also on the efficiency, transparency, and security of the supply chains through which medicines reach patients. More recent research on pharmaceutical supply chain management has emphasized the importance of coordinated governance, operational resilience, and improved information sharing in addressing distribution vulnerabilities (Alfaouri et al., 2025). Consequently, strengthening pharmaceutical supply chain integrity has become a strategic priority for healthcare organizations, pharmaceutical manufacturers, regulatory authorities, and policymakers seeking to maintain medicine quality and public confidence in healthcare delivery.

Pharmaceutical supply chain integrity encompasses the preservation of product identity, authenticity, quality, traceability, and accountability throughout the movement of medicines from manufacturing facilities to patients. A secure pharmaceutical supply chain should provide

reliable information about product origin, manufacturing details, batch identification, ownership transfers, storage conditions, and authorized distribution pathways. Weaknesses in these processes can increase the likelihood of substandard or falsified medicines entering legitimate markets and may also facilitate the unauthorized redistribution of genuine pharmaceutical products. It is important to distinguish between substandard medicines, which fail to meet established quality specifications, and falsified medicines, which deliberately misrepresent their identity, composition, or source. Drug diversion represents a related but distinct challenge involving the movement of legitimately manufactured medicines into unauthorized channels. These problems may result in therapeutic failure, avoidable adverse events, financial losses, and reduced confidence in healthcare institutions. The consequences are particularly concerning for medicines used in the treatment of infectious diseases, chronic illnesses, cancer, and other serious medical conditions. Ozawa et al. (2018), in a systematic review and meta-analysis, demonstrated the substantial public health and economic implications of substandard and falsified medicines in low- and middle-income countries. Lima and Yonamine (2023) further highlighted the need for coordinated prevention strategies involving

pharmaceutical regulation, quality surveillance, and supply chain security. These findings indicate that pharmaceutical integrity cannot be achieved through manufacturing quality assurance alone. Instead, effective protection requires continuous monitoring, authenticated transactions, reliable documentation, and coordinated institutional responsibility across the entire distribution network.

India provides an especially relevant setting for examining these challenges because of its substantial role in global pharmaceutical manufacturing, generic medicine production, and international pharmaceutical trade. The country's pharmaceutical distribution system connects large manufacturing organizations with regional distributors, carrying and forwarding agents, wholesale stockists, healthcare institutions, independent pharmacies, and increasingly digital service providers. While this network supports extensive medicine availability, differences in organizational resources, technological adoption, and documentation practices can complicate the maintenance of consistent product traceability. Recent research by Deepthy and Edwin (2026), involving 200 pharmaceutical supply chain stakeholders, examined digital infrastructure, data governance, serialization capability, and technology adoption in relation to track-and-trace readiness in India. Their work highlights the importance of organizational and technological preparedness when developing integrated pharmaceutical monitoring systems. At the policy level, India has introduced measures intended to improve medicine identification and regulatory oversight. The Central Drugs Standard Control Organisation (CDSCO) implemented barcode or Quick Response (QR) code requirements for 300 specified pharmaceutical formulation brands manufactured from August 2023 onward. In June 2026, the Ministry of Health and Family Welfare announced an expansion of Schedule H2 to include vaccines, antimicrobials, anti-cancer medicines, and specified narcotic and psychotropic drugs, with phased implementation beginning in July 2027. These developments demonstrate increasing regulatory attention to product identification and traceability, although compliance requirements alone cannot establish the effectiveness of authentication systems in practice (CDSCO, 2023; Ministry of Health and Family Welfare, 2026). The Indian pharmaceutical sector therefore offers an important opportunity to investigate how technological readiness, institutional coordination, and regulatory modernization can strengthen supply chain integrity while accommodating the operational diversity of domestic and international medicine distribution.

Regulatory governance and institutional collaboration are equally essential for addressing vulnerabilities within pharmaceutical distribution networks. Effective supply chain security depends on the ability of regulatory authorities to inspect manufacturing facilities, investigate suspected quality failures, verify distribution records, and coordinate corrective action when potentially unsafe medicines are identified. The World Health Organization (2025), in its evaluation of the Member State mechanism on substandard and falsified medical products, emphasized the importance of international cooperation

and institutional approaches to addressing medicine-quality threats. In India, the CDSCO works with state drug regulatory authorities to supervise pharmaceutical quality and enforce relevant legal requirements. According to the Ministry of Health and Family Welfare (2025), risk-based inspections, regulatory enforcement actions, drug-quality alerts, and laboratory information systems form part of the country's approach to preventing the circulation of substandard and spurious medicines. Nevertheless, regulatory effectiveness depends on the consistency of implementation, availability of trained personnel, timely information exchange, and responsiveness of individual supply chain participants. The expansion of pharmaceutical e-commerce further requires attention to authorized sellers, prescription verification, procurement records, and distribution accountability. At the organizational level, supplier qualification, inventory reconciliation, temperature monitoring, periodic audits, product recall procedures, and secure transaction documentation can complement regulatory inspection and digital authentication. These measures are particularly important because falsification, accidental quality deterioration, and diversion of genuine medicines involve different mechanisms and therefore require distinct preventive responses. A comprehensive pharmaceutical security framework should integrate preventive controls, early detection, incident investigation, and corrective action across both conventional and digitally enabled distribution systems (World Health Organization, 2025; Ministry of Health and Family Welfare, 2025).

Despite growing academic and regulatory attention to pharmaceutical supply chain security, existing research has largely examined drug authentication technologies, counterfeit medicine prevention, and distribution management as separate areas of investigation. Limited integrated analysis is available concerning the interaction between technological capabilities, organizational practices, and regulatory challenges within India's pharmaceutical distribution system. This review contributes to the existing literature by synthesizing evidence on therapeutic-category vulnerabilities, drug diversion mechanisms, digital authentication systems, and regulatory risk mitigation strategies within a unified analytical framework. Unlike studies focusing exclusively on individual technologies or counterfeit detection, the present review considers how serialization, QR-code verification, blockchain-based traceability, supplier authentication, and regulatory coordination can collectively support pharmaceutical supply chain integrity. Furthermore, the study identifies implementation barriers and areas requiring additional empirical investigation. By integrating technological, operational, and governance perspectives, the review aims to provide a foundation for developing practical strategies to improve medicine traceability, strengthen distribution accountability, and support pharmaceutical supply chain resilience in India.

2. REVIEW OF LITERATURE

Edwin (2026) investigated the technological and organizational factors influencing pharmaceutical track-and-trace readiness in India. The researchers collected

primary data from 200 pharmaceutical supply chain stakeholders and employed correlation and regression analysis to evaluate digital infrastructure, data governance, serialization, and technology adoption. The findings revealed that digital infrastructure and data governance significantly predicted track-and-trace readiness, explaining 51.9% of its variance. Serialization and technology adoption capabilities explained an additional model's 17.8% of variance. The study emphasized that effective pharmaceutical traceability requires coordinated technological development, reliable information management, and stakeholder participation to strengthen supply chain transparency and regulatory compliance

Sahoo (2026) examined pharmaceutical supply chain resilience against counterfeiting through the perspective of proactive organizational strategies. The study explored how organizational commitment to anti-counterfeiting, collaboration among supply chain participants, Industry 4.0-enabled counterfeit detection, and government regulation contribute to pharmaceutical security. Its research framework positioned counterfeit prevention as a collective responsibility requiring coordination between business organizations and regulatory institutions. The study is relevant to pharmaceutical supply chain integrity because it connects technological detection capabilities with organizational preparedness and collaborative governance. It provides a foundation for examining how integrated anti-counterfeiting strategies can support stronger, more responsive pharmaceutical distribution systems and improve resilience against emerging threats. Akram et al. (2024) examined blockchain technology as a potential solution for improving pharmaceutical supply chain transparency, security, and product traceability. The authors conducted a literature review covering research published between January 2017 and September 2023. Their analysis highlighted blockchain's capacity to maintain shared transaction records and support the verification of pharmaceutical product movement across manufacturers, distributors, pharmacies, and healthcare institutions. The study identified potential benefits relating to data integrity, accountability, product recalls, and communication among authorized stakeholders. The researchers concluded that blockchain-based systems could strengthen pharmaceutical supply chain management through improved transaction visibility and auditable records of medicine distribution.

Dhoke (2025) examined emerging technological developments and regulatory challenges associated with pharmaceutical supply chain management and serialization. The study discussed the potential contributions of digital authentication, product identification, and electronic traceability to improving pharmaceutical distribution security. Particular attention was given to technologies such as blockchain, artificial intelligence, radio-frequency identification, and the Internet of Things. The review also identified challenges related to implementation costs, regulatory differences, system interoperability, and cybersecurity. The study highlighted the importance of integrating technological innovation with regulatory compliance and organizational coordination. These observations are relevant to

developing effective authentication and traceability strategies within India's pharmaceutical distribution network.

Yonamine (2023) reviewed the global challenges associated with counterfeit medicines, emphasizing their consequences for public health, pharmaceutical regulation, and medicine supply chain security. The study examined how falsification of medicine identity, origin, and distribution history threatens product authenticity and patient safety. Particular attention was given to regulatory weaknesses and socioeconomic conditions that can facilitate counterfeit pharmaceutical circulation, especially in developing regions. The authors discussed the importance of legislative measures, effective regulatory enforcement, and coordinated preventive strategies. Their review provides a foundation for understanding why pharmaceutical authentication, reliable distribution records, and institutional oversight are essential components of medicine quality assurance and counterfeit prevention.

Research Gap

Although recent studies have examined pharmaceutical supply chain security, drug authentication, serialization, and digital traceability, significant research gaps remain regarding their integrated implementation in India. Existing literature primarily emphasizes technological innovations and regulatory frameworks, while limited attention has been given to operational challenges across manufacturers, wholesalers, distributors, and retail pharmacies. Furthermore, empirical evidence concerning the effectiveness, affordability, and adoption of blockchain, QR-code authentication, and real-time tracking systems remains insufficient. There is also a need to investigate stakeholder coordination, data interoperability, and regulatory compliance. Therefore, this study addresses these gaps by examining integrated strategies for improving pharmaceutical traceability, minimizing distribution risks, and strengthening supply chain integrity in India.

Objectives of the Study

To identify major vulnerabilities affecting pharmaceutical distribution and product authenticity in India.

To examine the role of serialization, QR codes, blockchain, and digital tracking technologies in pharmaceutical authentication.

To analyze drug diversion mechanisms and operational risks across pharmaceutical supply chain stages.

To evaluate regulatory and organizational challenges associated with pharmaceutical traceability.

To propose integrated risk mitigation strategies for improving supply chain transparency and medicine security.

3. METHODOLOGY

3.1 Research Design

The present study adopts a narrative literature review approach to examine pharmaceutical supply chain integrity in India, with particular emphasis on drug authentication, medicine traceability, distribution vulnerabilities, regulatory compliance, and risk mitigation

strategies. The review framework integrates evidence from academic research, pharmaceutical regulatory publications, and institutional reports to develop an understanding of the technological, organizational, and governance factors influencing pharmaceutical security. A narrative review design was selected to facilitate the examination of diverse research findings and policy perspectives relating to pharmaceutical supply chain management.

3.2 Literature Search Strategy

The literature search framework covers relevant research available through Google Scholar, PubMed, ScienceDirect, and other recognized academic sources, together with publications issued by the World Health Organization (WHO) and the Central Drugs Standard Control Organisation (CDSCO). The proposed search terms include "pharmaceutical supply chain integrity," "drug authentication," "medicine traceability," "pharmaceutical serialization," "counterfeit medicines in India," "drug diversion," "blockchain in pharmaceutical supply chains," and "pharmaceutical risk mitigation."

Boolean operators such as AND and OR may be applied to combine related concepts and identify relevant publications. For example, the search expression ("pharmaceutical supply chain" OR "medicine distribution") AND ("authentication" OR "traceability" OR "serialization") can be used to identify research examining technological approaches to pharmaceutical security. The literature search should prioritize recent publications from 2020 to 2026 while retaining earlier foundational studies where necessary.

3.3 Inclusion and Exclusion Criteria

Studies are eligible for inclusion when they examine pharmaceutical supply chain management, medicine authentication, traceability technologies, counterfeit medicine prevention, drug diversion, or regulatory risk management. Preference is given to peer-reviewed research articles, review papers, and authoritative regulatory publications relevant to India or comparable pharmaceutical distribution systems.

Publications are excluded when they lack relevance to pharmaceutical supply chain security, provide insufficient

methodological or conceptual information, or focus exclusively on unrelated clinical and therapeutic outcomes. Duplicate publications should be removed during screening. The relevance of the remaining sources should be evaluated according to their contribution to the study objectives.

3.4 Data Extraction and Thematic Classification

Relevant information is organized according to study authorship, publication year, research objectives, methodological approach, major findings, and implications for pharmaceutical supply chain integrity. The literature is classified into five principal themes: therapeutic-category vulnerabilities, distribution-stage risks, drug diversion mechanisms, digital authentication and traceability technologies, and regulatory governance. This thematic classification provides a structured basis for comparing pharmaceutical security challenges and evaluating proposed preventive interventions. Particular attention is given to technological applicability, operational feasibility, regulatory requirements, and coordination among pharmaceutical supply chain stakeholders.

3.5 Data Synthesis and Interpretation

A qualitative thematic synthesis approach is employed to compare findings and recommendations reported across the reviewed literature. The analysis focuses on identifying recurring supply chain vulnerabilities, evaluating the potential contributions and limitations of authentication technologies, and examining organizational and regulatory strategies for reducing pharmaceutical distribution risks.

The findings are presented through descriptive analysis, comparative tables, and a conceptual review framework. Because the study is a narrative review, it does not involve primary data collection, statistical meta-analysis, or laboratory testing. The qualitative risk classifications represent analytical interpretations rather than measured prevalence estimates. The synthesis is intended to identify practical opportunities for strengthening pharmaceutical traceability, product verification, and regulatory coordination in India.

Figure 1. Overview of the Comprehensive Review Process



4. Results

4.1 Therapeutic Category–Specific Vulnerabilities in Pharmaceutical Supply Chains

The vulnerability of pharmaceutical products to falsification and unauthorized distribution is influenced by several interacting factors, including market demand, product value, distribution complexity, and the strength of authentication controls. Different therapeutic categories may face distinct forms of supply chain exposure, making a uniform approach to pharmaceutical security insufficient.

Medicines purchased frequently and distributed in large quantities require effective batch monitoring and supplier

verification. Conversely, specialized medicines with high acquisition costs may warrant additional product-level authentication and transaction monitoring. The growth of online pharmaceutical sales further emphasizes the importance of verifying distribution channels and maintaining reliable product histories. The available source material does not establish nationally representative, category-specific counterfeit prevalence rates. Therefore, Table 1 identifies qualitative vulnerabilities and suggested monitoring priorities rather than numerical prevalence estimates

Table 1. Qualitative Supply Chain Vulnerabilities and Monitoring Priorities by Drug Category

Drug Category	Qualitative Risk Consideration	Monitoring Priority
Anti-infectives	High distribution volume and quality sensitivity	Batch authentication
Cardiovascular and Antidiabetic Medicines	Continuous demand and repeated dispensing	Supplier verification
Oncology Medicines	High product value and specialized handling	Unit-level traceability
CNS Medicines	Potential unauthorized redistribution and misuse	Transaction monitoring
Pediatric Medicines	Dosage sensitivity and formulation-specific risks	Quality verification

4.2 Drug Category–Wise Analysis

Pharmaceutical authentication requirements differ across therapeutic categories because medicines vary in price, handling requirements, distribution frequency, and potential consequences of quality failure. Understanding these differences can help pharmaceutical organizations prioritize preventive controls. Anti-infective medicines require particular attention because poor-quality products may compromise treatment outcomes and contribute to antimicrobial resistance. Strong procurement controls, batch verification, and timely reporting of suspected quality defects are important preventive measures.

Cardiovascular and antidiabetic medicines are frequently used for long-term disease management. Continuous supply requirements create a need for dependable sourcing, accurate inventory records, and consistent verification of products received from distributors.

Oncology medicines present distinct supply chain challenges due to their specialized therapeutic

applications, relatively high value in many product segments, and sensitivity to handling conditions. Authentication mechanisms, secure distribution arrangements, and appropriate storage monitoring are particularly relevant to these medicines. Central nervous system medicines, especially products subject to additional prescription or controlled-substance requirements, require effective inventory reconciliation and dispensing oversight. These controls can help identify unauthorized product movement without conflating diversion of genuine medicines with pharmaceutical falsification.

Paediatric medicines require careful attention to formulation integrity, dosage accuracy, labelling, and storage conditions. Product verification and procurement from authorized suppliers are essential because medication-quality failures can have serious consequences for vulnerable patients

Table 2. Therapeutic Categories, Supply Chain Risks and Preventive Strategies

Therapeutic Category	Primary Supply Chain Concern	Proposed Preventive Strategy
Anti-infectives	Product-quality failure and high-volume distribution	Batch-level verification
Cardiovascular	Repeated procurement and distribution	Authorized supplier audits
Oncology	High-value products and specialized handling	Serialization and secure logistics
CNS Drugs	Diversion and unauthorized dispensing	Inventory reconciliation
Paediatric Medicines	Formulation integrity and labelling	Enhanced quality assurance

4.3 Supply Chain Vulnerabilities in India

Pharmaceutical distribution in India involves multiple operational stages, including manufacturing, warehousing, transportation, wholesale distribution, retail dispensing, and digital commerce. Each stage performs an essential function in maintaining medicine availability, but the involvement of numerous independent organizations can complicate product tracking and regulatory supervision. Manufacturing-stage vulnerabilities may arise from inadequate documentation, packaging inconsistencies, insufficient quality controls, or failures in batch identification. Strong manufacturing practices and reliable product records are therefore necessary to establish a trustworthy starting point for downstream traceability. Wholesale distribution can introduce additional

uncertainty when products move through multiple intermediaries with different information systems. Incomplete transaction records or inconsistent supplier verification can make it difficult to reconstruct product movement during investigations. Retail pharmacies and healthcare institutions represent the final stages of medicine distribution. Product authentication at these points can help identify discrepancies before medicines are dispensed to patients. However, effective verification requires access to reliable product information and appropriate staff training. Digital pharmaceutical platforms create further challenges involving seller verification, prescription authentication, and the identification of legitimate product sources. Cross-border pharmaceutical trade similarly requires coordination among regulatory and customs authorities

Table 3. Supply Chain Vulnerabilities

Supply Chain Stage	Key Vulnerability	Recommended Control
Manufacturing	Incomplete product identification records	Serialization and quality audits
Wholesale	Limited transaction visibility	Digital track-and-trace
Retail Pharmacies	Inadequate product verification	Barcode authentication
Online Pharmacies	Unverified suppliers and product sources	Platform compliance monitoring
Cross-Border Trade	Complex shipment documentation	Regulatory data exchange

4.4 Mechanisms of Drug Diversion

Drug diversion refers to the unauthorized movement of legitimately manufactured medicines away from their intended distribution or use. Unlike pharmaceutical falsification, diversion does not necessarily involve alteration of the medicine itself. Nevertheless, diverted products may enter channels where storage conditions, product histories, and dispensing practices cannot be adequately verified. Warehouse losses and transportation theft represent potential sources of unauthorized pharmaceutical circulation. Medicines removed from controlled storage facilities may subsequently be redistributed without proper documentation, creating challenges for product accountability. Unauthorized resale and irregular

distribution transactions can also weaken supply chain transparency. When products move outside approved contractual or regulatory arrangements, the original supplier may lose visibility over subsequent handling and ownership. Institutional diversion may occur through inventory discrepancies, unauthorized dispensing, or weaknesses in pharmaceutical stock management. Healthcare facilities can reduce these risks through controlled access, inventory reconciliation, and transaction auditing. Prescription manipulation presents a further concern for medicines subject to prescription requirements. Effective prescription verification and appropriate dispensing controls are therefore important elements of diversion prevention

Table 4. Common Diversion Pathways and Preventive Measures

Diversion Mechanism	Potential Leakage Point	Preventive Measure
Warehouse theft	Storage and transportation	Access controls and inventory audits
Unauthorized resale	Wholesale distribution	Transaction verification
Hospital diversion	Institutional pharmacies	Stock reconciliation
Prescription manipulation	Retail dispensing	Prescription validation

4.5 Emerging Trends and Patterns

Pharmaceutical supply chain security is increasingly influenced by digital technologies, changing distribution practices, and the growing importance of real-time product information. Authentication systems are evolving beyond conventional packaging inspection toward electronic identification and transaction-based verification. Serialization allows individual saleable units or designated packaging levels to carry unique identification information. When supported by suitable information systems, serialized records can help organizations verify product identities and investigate irregular distribution events. Blockchain-based solutions have also attracted research interest because of their potential to provide shared,

tamper-resistant transaction histories. However, their practical effectiveness depends on the reliability of recorded information, implementation costs, interoperability, and participation across organizations. Artificial intelligence and data analytics may support the identification of unusual ordering patterns, unexplained inventory changes, and suspicious distribution activity. These applications require validated data and appropriate human oversight to avoid inaccurate conclusions. Digital pharmacy expansion creates opportunities for improved accessibility while simultaneously increasing the importance of seller authentication and platform accountability. Regulatory modernization and collaboration among supply chain participants will therefore remain central to pharmaceutical security

Table 5. Emerging Technologies and Trends in Pharmaceutical Supply Chain Security

Emerging Trend	Potential System-Level Impact	Implementation Consideration
Pharmaceutical Serialization	Improved product identification	Data accuracy
Blockchain Traceability	Shared transaction visibility	Interoperability and cost
AI-Based Monitoring	Detection of unusual transactions	Data quality and validation
Digital Pharmacy Expansion	Greater access and new oversight needs	Seller verification
Regulatory Digitalization	Faster information exchange	Institutional coordination

5.DISCUSSION

The review highlights pharmaceutical supply chain integrity as a multidimensional issue involving product authenticity, operational transparency, regulatory accountability, and technological capability. Maintaining medicine quality requires more than detecting falsified products at the point of sale. It involves establishing reliable controls throughout manufacturing, storage, distribution, procurement, and dispensing. One important consideration is the relationship between therapeutic-product characteristics and authentication priorities. Medicines distributed in large volumes require efficient verification systems capable of handling frequent transactions, whereas expensive specialty products may benefit from more detailed product-level tracking. Controlled medicines require additional safeguards against unauthorized movement. These differences indicate that pharmaceutical security measures should be adapted to the characteristics of individual product categories rather than applied uniformly. Digital traceability offers an important opportunity to improve supply chain visibility. Serialization and electronic transaction records can help organizations identify where products originated, document their movement, and investigate discrepancies. However, the presence of a barcode or digital identifier does not independently establish product authenticity. Effective authentication requires verification against trustworthy records and procedures for handling duplicated, invalid, or suspicious identifiers. The adoption of advanced technologies also introduces operational challenges.

Pharmaceutical companies and distribution partners may differ considerably in their technical infrastructure, workforce capabilities, and financial resources. Smaller distributors and retail pharmacies may face difficulties integrating sophisticated information systems into existing operations. Therefore, implementation strategies should consider affordability, training, system compatibility, and ongoing maintenance. Regulatory coordination remains equally important. Pharmaceutical supply chains involve organizations operating across different administrative and geographical boundaries. Effective oversight depends on consistent documentation, clear responsibilities, appropriate inspection practices, and reliable communication between regulatory authorities and industry participants. Digital systems may improve the availability of information, but they cannot substitute for enforcement capacity or sound institutional governance. Drug diversion presents an additional challenge because unauthorized distribution can involve genuine medicines. Authentication systems designed only to identify falsified packaging may fail to detect legitimate products moving through unauthorized channels. Consequently, transaction monitoring, inventory reconciliation, and supplier due diligence should complement product-level verification. The development of online pharmaceutical marketplaces further demonstrates the need for integrated security strategies. Digital platforms require effective controls for identifying authorized sellers, validating prescription requirements, and maintaining accountability for product sourcing and delivery. Regulatory supervision should

address both conventional distribution networks and technology-enabled pharmaceutical commerce.

A comprehensive risk mitigation strategy should combine preventive, detective, and corrective controls. Preventive measures include supplier qualification, secure storage, employee training, and authenticated procurement. Detective measures include product verification, inventory audits, and monitoring of irregular transactions. Corrective measures include product quarantine, incident reporting, recall coordination, and investigation of identified vulnerabilities. The analytical findings also suggest that pharmaceutical supply chain resilience depends on collaboration. Manufacturers, logistics providers, wholesalers, pharmacies, hospitals, technology developers, and regulatory authorities each possess information necessary for maintaining product accountability. Greater interoperability and clearly defined information-sharing procedures could improve the speed and effectiveness of responses to suspicious pharmaceutical activity. Nevertheless, the conclusions of this narrative review should be interpreted within its methodological limitations. The analysis does not establish the national prevalence of falsified medicines, measure the effectiveness of particular technologies, or demonstrate that any individual intervention has reduced counterfeit circulation in India. These questions require empirical investigation using verified regulatory records, field studies, product testing, and implementation evaluations.

Future research should assess the cost-effectiveness of serialization, the feasibility of interoperable tracking platforms, the adoption barriers faced by smaller supply chain participants, and the effectiveness of digital authentication in real-world Indian pharmaceutical distribution settings. Overall, the review supports an integrated approach in which technological verification, organizational accountability, and regulatory governance function as complementary components of pharmaceutical supply chain security. Sustainable improvements are likely to depend on coordinated implementation rather than isolated technological investments.

5.1 Limitations of the Study

This study is based on a narrative synthesis of existing literature and does not include primary data collection, laboratory testing, or direct observation of pharmaceutical distribution practices. Consequently, the analysis cannot establish the prevalence of counterfeit medicines in India or quantitatively determine the effectiveness of individual authentication technologies. The qualitative risk

classifications and proposed interventions are conceptual and may not reflect differences among geographical regions, therapeutic markets, or pharmaceutical organizations. Future studies should incorporate empirical data, stakeholder interviews, regulatory inspection records, and technology implementation assessments to validate the proposed risk mitigation strategies.

6.CONCLUSION

Pharmaceutical supply chain integrity is essential for ensuring the safety, authenticity, and reliable availability of medicines within India's healthcare system. The increasing complexity of pharmaceutical distribution, participation of multiple intermediaries, expansion of digital commerce, and continuing risks associated with unauthorized product movement create substantial challenges for maintaining effective oversight. This review identifies product authentication, transaction transparency, supplier verification, and regulatory coordination as important components of pharmaceutical security. Different therapeutic categories require tailored risk management approaches because their distribution characteristics, economic value, handling requirements, and potential consequences of quality failure vary considerably.

Technologies such as serialization, barcode verification, electronic track-and-trace platforms, and data-driven monitoring offer potential mechanisms for improving product visibility and detecting irregular transactions. However, technological solutions are most effective when supported by accurate information, appropriate infrastructure, trained personnel, and consistent regulatory supervision. The review also emphasizes that counterfeit prevention and drug diversion control should be addressed through complementary strategies. While authentication helps establish product identity, effective diversion prevention requires secure inventory management, transaction monitoring, and oversight of authorized distribution channels.

Strengthening pharmaceutical supply chain integrity in India therefore requires collaboration among manufacturers, distributors, healthcare providers, technology organizations, and regulatory authorities. Long-term progress will depend on practical implementation, institutional accountability, and continued evaluation of preventive interventions. A coordinated and risk-based approach can contribute to improved patient protection, more reliable pharmaceutical distribution, and greater confidence in India's domestic and international medicine supply networks

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