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Enhancing Controlled Substance Security in Community Pharmacies with AI and Technology in Nigeria: A Review

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Abstract

The increasing concern over controlled substance diversion and misuse has highlighted the need for more effective security measures in community pharmacies, particularly in developing countries such as Nigeria. This review explores the role of artificial intelligence (AI), blockchain, and the Internet of Things (IoT) in enhancing the security of controlled substances within pharmacies. The paper discusses the importance of securing controlled substances, the limitations of traditional security methods, and the emerging technological innovations that can address these vulnerabilities. It also examines the regulatory frameworks in Nigeria, the challenges faced in adopting advanced technologies, and global trends in drug diversion. AI-powered predictive analytics, blockchain for transparency, and IoT-enabled real-time monitoring systems are identified as promising solutions for improving security, reducing human error, and ensuring compliance with regulatory standards. The review also highlights the challenges of technology adoption, including high costs, data privacy concerns, and resistance to change. Finally, the paper presents recommendations for future research, emphasizing the need for studies on the long-term impacts, cost-benefit analyses, and the integration of advanced technologies into existing pharmacy systems. The findings suggest that adopting these technologies is crucial for the future security of controlled substances in pharmacies and the protection of public health.

Keywords: AI, controlled substances, drug diversion, pharmacy security, real-time monitoring and regulatory frameworks.

1. Introduction

Controlled substances, encompassing medications or drugs with the potential for abuse, dependency, and illicit distribution, represent a critical focus in public health and safety. Community pharmacies, serving as the primary touchpoints for the management and dispensation of these substances, bear the responsibility of ensuring their secure handling (El-Dahiyat et al., 2023). This includes measures to prevent unauthorized access, theft, diversion,

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and misuse, all while adhering to strict regulatory standards. Effective security mechanisms are indispensable not only for safeguarding public health but also for upholding the integrity and trustworthiness of the pharmaceutical supply chain.

Drug diversion, the redirection of controlled substances from their intended medical use to illicit channels, poses a multifaceted threat to public health and safety in Nigeria and beyond. The consequences of diversion are wide-reaching, contributing significantly to the addiction crisis and exacerbating substance abuse disorders (Lindquist-Grantz et al., 2021). Additionally, illicit consumption of diverted drugs often leads to overdoses, adverse drug reactions, and fatalities, placing immense strain on healthcare systems (Dhapkas et al., 2024). The illegal distribution of these substances also fuels organized crime, theft, and violence, destabilizing communities. Moreover, the economic costs of addressing addiction, enforcing drug laws, and managing drug-related health crises place a substantial financial burden on governments and healthcare systems. These impacts highlight the urgent need for robust systems to mitigate diversion and its ripple effects on public health and safety.

In Nigeria, the regulation of controlled substances falls under the purview of agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) and the Pharmacy Council of Nigeria (PCN). These agencies enforce critical regulations designed to control the production, distribution, and usage of controlled drugs:

1. Pharmacy Practice Act: Ensures the professional and operational licensing of pharmacies and pharmacists.
2. Drug Control Laws: Defines schedules for controlled substances, outlines handling requirements, and stipulates penalties for violations.
3. Inventory Management Guidelines: Mandates accurate record-keeping, regular audits, and timely reporting of discrepancies.

Despite these regulations, enforcement challenges, technological constraints, and inadequate monitoring infrastructure limit their effectiveness. Addressing these gaps is vital for improving the security of controlled substances. Historically, community pharmacies in Nigeria have relied on conventional approaches to secure controlled substances, such as:

1. Physical Security Measures: Safes, lockable cabinets, and restricted access zones.
2. Manual Inventory Management: Logs documenting stock levels, sales, and disposal activities.
3. Staff Training: Educating employees on regulatory compliance and the risks of drug diversion.
4. Audits and Inspections: Periodic reviews by regulatory authorities to verify adherence to legal requirements.

Though these methods form the foundation of pharmacy security, they are vulnerable to human error, inefficiencies, and tampering. These shortcomings necessitate a shift towards modern, technology-driven solutions.

Technological innovations, particularly Artificial Intelligence (AI), offer transformative solutions to address the complexities and limitations of traditional security measures. Key advancements include:

1. AI-Powered Surveillance: Smart cameras with facial recognition and behavioural analytics to detect and respond to suspicious activities (Amingad et al., 2023).
2. Automated Inventory Systems: AI-integrated tools for real-time stock tracking, anomaly detection, and access control (Jasmitha et al., 2023).
3. Blockchain Technology: Immutable and transparent ledgers to monitor the movement of drugs within the supply chain (Shete et al., 2024).
4. IoT-Enabled Devices: Smart locks and sensors for enhanced storage security and breach alerts (Bhattacharya et al., 2022).
5. Predictive Analytics: AI-driven models to identify trends in drug diversion and guide preventive measures (Knight et al., 2022).

These technologies not only mitigate risks but also ensure efficiency, compliance with regulatory standards, and adaptability to evolving threats.

1.1. Purpose of the Paper

This review examines the potential of AI and other advanced technologies to enhance the security of controlled substances in community pharmacies across Nigeria. The specific objectives are:

1. Analyze the limitations of traditional methods and the risks posed by drug diversion
2. Highlight cutting-edge tools and techniques for improving pharmacy security.
3. Offer actionable recommendations for adopting advanced technologies within the Nigerian context.

1.2. Scope of the Paper

The scope includes a detailed analysis of existing security practices in Nigerian pharmacies, an assessment of the regulatory landscape, and the development of a framework for technology-driven improvements. Addressing these dimensions, this paper aims to provide a comprehensive roadmap for enhancing the security of controlled substances in community pharmacies, ensuring better compliance, reducing diversion risks, and ultimately safeguarding public health in Nigeria.

2. Literature Review

2.1. Importance of Controlled Substance Security in Community Pharmacies

Controlled substances are central to many therapeutic regimens, yet their potential for misuse and dependency makes their security paramount. Community pharmacies, as intermediaries between manufacturers and patients, are key in maintaining this security. Studies emphasize that robust measures in pharmacies are essential not only for ensuring the safe dispensation of these drugs but also for mitigating public health crises such as addiction and overdose epidemics (Green et al., 2022; Skoy et al., 2022). Secure handling of controlled substances preserves the trust of the public and maintains the integrity of the pharmaceutical supply chain. Additionally, preventing theft and diversion at the pharmacy level directly reduces the availability of drugs in illicit markets (Knight et al., 2022).

2.2. Vulnerabilities of Traditional Security Measures

Traditional methods, including physical barriers, manual inventory management, and periodic audits, have been the cornerstone of controlled substance security for decades. However, these approaches are increasingly shown to be inadequate in addressing modern challenges. Human errors in record-keeping, tampering with physical security systems, and limited oversight in storage and distribution are significant vulnerabilities (Zhang et al., 2020). Research highlights that such limitations contribute to a substantial portion of drug diversion cases in pharmacies, with internal theft by staff being a notable concern (Hussein et al., 2021). Moreover, these systems lack adaptability to emerging threats, such as cyberattacks targeting inventory records or advanced methods of physical breach.

2.3. Overview of AI and Technology in Healthcare Security

Artificial Intelligence (AI) and other advanced technologies are reshaping healthcare security, offering solutions that transcend the limitations of traditional methods. AI-powered surveillance systems, equipped with facial recognition and behaviour analytics, can detect suspicious activities in real time, reducing the likelihood of theft or diversion (Amingad et al., 2023). Automated inventory systems integrated with AI enable accurate stock tracking, identify discrepancies instantly, and provide predictive insights to prevent stockouts or misuse (Jasmitha et al., 2023). Blockchain technology, with its immutable and transparent record-keeping, is another innovation that ensures secure tracking of controlled substances across the supply chain (Shete et al., 2024). Collectively, these advancements not only enhance security but also streamline operations, ensuring compliance with regulatory frameworks more efficiently.

2.4. Global Trends in Drug Diversion

Drug diversion is a global challenge that transcends borders, with trends varying based on socioeconomic factors, regulatory frameworks, and healthcare systems. Developed countries, such as the United States and Canada, report significant diversion incidents due to overprescription and poor monitoring mechanisms (Orpana et al., 2021; Puac-Polanco et al., 2020). Conversely, in developing nations like Nigeria, weak regulatory enforcement and inadequate infrastructure exacerbate the issue. A notable trend is the increasing role of online platforms in facilitating the illegal distribution of controlled substances, complicating traditional enforcement strategies (Fuller et al., 2024). Mackey & Cuomo, (2020) advocate for the harmonization of global policies and the adoption of advanced monitoring technologies to counter these trends effectively.

2.5. Regulatory Measures and Best Practices in Community Pharmacies

Effective regulatory measures are fundamental to curbing drug diversion and ensuring controlled substance security. Countries with stringent regulations, such as the United Kingdom and Australia, demonstrate lower rates of diversion due to comprehensive laws and robust enforcement mechanisms (Emanuel et al., 2020). Best practices include mandatory staff training, regular audits, electronic inventory management, and the use of advanced security technologies like AI and IoT-enabled systems. In Nigeria, regulatory bodies such as NAFDAC and the PCN play crucial roles in establishing guidelines for controlled substance management.

However, challenges in enforcement and resource constraints hinder the full implementation of these regulations (Itua et al., 2024).

Global case studies show that the integration of regulatory oversight with technology can lead to significant improvements. For instance, the use of AI in pharmacy operations in China has reduced inventory discrepancies and enhanced customer satisfaction by 42.4% (Shen et al., 2024). Similarly, blockchain implementation in supply chain management has eliminated tampering incidents in several European countries (Kowalski & Esposito, 2023). Adopting these best practices in Nigeria could address current gaps and strengthen the security of controlled substances.

3. Current Security Measures in Community Pharmacies

Effective security in community pharmacies is essential for preventing unauthorized access, theft, and diversion of controlled substances. Current measures employed by pharmacies typically involve a combination of manual protocols, physical storage systems, record-keeping practices, and surveillance. This section examines these measures, highlighting their strengths and limitations.

3.1Manual Security Protocols

Manual security protocols involve processes such as restricting access to certain areas of the pharmacy, maintaining detailed schedules for the handling and dispensing of controlled substances, and enforcing staff-only access zones. These measures are often paired with staff training programs to ensure that employees understand the importance of controlled substance security and their role in maintaining it (Ceballos et al., 2020). While these protocols provide a foundational level of control, they rely heavily on human vigilance, which can lead to errors or lapses. For example, failure to adhere to established procedures or intentional breaches by staff can compromise the system. Additionally, manual protocols are time-intensive and may lack the responsiveness needed to address emerging threats swiftly (Mensah et al., 2024).

3.2 Physical Storage and Locked Cabinets

Physical storage solutions such as safes, lockable cabinets, and restricted storage areas are common in community pharmacies. These systems are designed to secure controlled substances physically, limiting access to authorized personnel only. Lockable cabinets are often strengthened by access codes or keycards, adding an extra layer of security (Wijaya et al., 2022). However, physical storage solutions are not immune to vulnerabilities. Keys can be stolen or duplicated, access codes may be shared or hacked, and cabinets can be tampered with if not routinely inspected. Furthermore, without integration with monitoring systems, breaches may go undetected until an audit or inventory check is conducted.

3.3 Manual Record-Keeping and Audits

Manual record-keeping involves logging the receipt, storage, dispensation, and disposal of controlled substances in physical ledgers or spreadsheets. Regular audits are conducted to reconcile inventory with recorded data and identify any discrepancies (Hammour et al., 2022). Although these measures help maintain accountability, they are prone to human error. Mistakes in data entry, intentional falsification, and delays in updating records can lead to inaccuracies

that hinder effective monitoring. Additionally, manual audits are often reactive, identifying issues after they occur rather than preventing them.

3.4 Surveillance Systems and Monitoring

Some community pharmacies employ basic surveillance systems, such as closed-circuit television (CCTV), to monitor storage areas and deter theft. These systems can capture evidence of unauthorized access or suspicious behaviour, which is valuable for investigations (Pisati et al., 2024). Despite their utility, traditional surveillance systems are largely passive, requiring manual review of footage to identify incidents. Without integration with advanced technologies like artificial intelligence, these systems are limited in their ability to detect real-time threats or alert staff to potential issues. Moreover, the effectiveness of surveillance depends on proper installation, regular maintenance, and monitoring, which may be inconsistent in resource-constrained settings (Lin & Pham, 2023).

4. AI and Technology Applications in Controlled Substance Security

Technological advancements in artificial intelligence (AI), blockchain, and the Internet of Things (IoT) offer transformative solutions to the challenges associated with controlled substance security in community pharmacies. These innovations enhance monitoring, accountability, and compliance while minimizing vulnerabilities inherent in traditional systems.

4.1 AI-Powered Predictive Analytics

AI-powered predictive analytics leverages machine learning algorithms to identify patterns, predict risks, and enable proactive measures in pharmacy operations.

4.1.1 Prescription Monitoring

AI systems can analyze prescription trends to detect irregularities that may indicate potential abuse or diversion. For instance, excessive prescriptions for controlled substances or patterns inconsistent with patient medical histories can be flagged for further review (May et al., 2020). This helps mitigate the risk of "doctor shopping" and fraudulent prescriptions.

4.1.2 Employee Behavior Analytics

AI tools can track employee activities to identify anomalies that may suggest insider threats. Behavioural analytics systems assess patterns such as repeated access to storage areas outside work hours or inconsistent handling of inventory (Hussein et al., 2021). This real-time analysis enables swift intervention.

4.1.3 Predictive Theft and Diversion Models

Machine learning models trained on historical data can predict theft or diversion risks by analyzing factors such as stock discrepancies, storage vulnerabilities, and external environmental risks (Knight et al., 2022). Predictive capabilities empower pharmacies to deploy preventive measures, reducing the likelihood of incidents.

4.2 Blockchain for Transparency and Traceability

Blockchain technology ensures immutable, transparent, and decentralized record-keeping, enhancing the traceability of controlled substances across the supply chain.

4.2.1 Immutable Record-Keeping

Blockchain creates tamper-proof records of every transaction involving controlled substances, from manufacturing to dispensation. This transparency discourages unauthorized alterations and provides an auditable trail (Shete et al., 2024).

4.2.2 Tracking and Tracing Substances

Pharmacies can use blockchain to trace the movement of controlled substances, ensuring accountability at every stage. This reduces the risk of diversion during transit or storage (Liu et al., 2021).

4.2.3 Smart Contracts for Compliance

Smart contracts embedded in blockchain systems automate compliance with regulatory requirements (Alikhani & Hamidi, 2021; Shete et al., 2024). For example, controlled substances cannot be dispensed without verifying patient eligibility or proper authorization.

4.3 IoT Devices for Real-Time Monitoring

IoT devices enhance real-time monitoring of controlled substances, providing additional layers of security and operational efficiency.

4.3.1 Smart Cabinets and Safes

Smart storage solutions equipped with IoT-enabled locks and access control systems ensure that only authorized personnel can access controlled substances (Bhattacharya et al., 2022). These cabinets can send alerts in case of unauthorized access attempts.

4.3.2 Environmental Monitoring

IoT sensors monitor environmental conditions such as temperature and humidity within storage areas to ensure compliance with regulatory standards for drug safety (Bhattacharya et al., 2022). Deviations from prescribed conditions trigger automated alerts for corrective actions.

4.3.3 Inventory Management

IoT-integrated inventory systems provide real-time updates on stock levels, reducing the risk of discrepancies and facilitating timely reordering of controlled substances (Bhattacharya et al., 2022).

4.4 AI-Driven Surveillance Systems

AI-driven surveillance systems incorporate advanced analytics to enhance security in pharmacy settings.

4.4.1 Facial Recognition

AI-powered facial recognition technology identifies authorized personnel and detects unauthorized individuals attempting to access restricted areas (Amingad et al., 2023). This reduces the likelihood of breaches and enhances accountability.

4.4.2 Behavioural Analysis

Behavioural analysis tools embedded in surveillance systems can detect suspicious activities, such as prolonged loitering near storage areas or unusual movement patterns. These systems can send real-time alerts for immediate investigation (Hussein et al., 2021).

5. Challenges in Adopting AI and Technology in Pharmacies

Although AI and other advanced technologies hold great promise for enhancing controlled substance security, their implementation in community pharmacies is fraught with challenges. These obstacles must be addressed to realize the full potential of these innovations in improving pharmacy operations and safeguarding public health.

5.1 Cost and Financial Investment

The adoption of AI, blockchain, and IoT technologies requires substantial financial investment and ethical consideration, and data privacy can be a significant barrier for many community pharmacies. These costs include purchasing equipment, integrating software, and maintaining new systems (Rammal et al., 2024). Smaller or independently owned pharmacies, in particular, may struggle to justify these expenses, especially in resource-constrained environments. Additionally, the long-term financial benefits of adopting such technologies, such as reduced losses from theft or enhanced efficiency, may not be immediately apparent, further deterring investment.

5.2 Data Privacy and Compliance Issues

The implementation of AI and IoT in pharmacies involves collecting and processing sensitive patient and operational data. Ensuring compliance with data privacy regulations, such as the Nigerian Data Protection Regulation (NDPR) and international standards like GDPR, presents a significant challenge (Grothen et al., 2020). Breaches in data security can lead to severe consequences, including loss of patient trust, legal penalties, and reputational damage. Pharmacies must ensure robust cybersecurity measures and align with privacy laws to protect against unauthorized access and misuse of data.

5.3 Integration with Existing Pharmacy Systems

Many pharmacies rely on legacy systems for inventory management, record-keeping, and prescription processing. Integrating new technologies like AI and blockchain with these

existing systems can be technically complex and costly (Grothen et al., 2020). Interoperability challenges, such as mismatched data formats and incompatible software, can hinder seamless adoption. Pharmacies may need to overhaul or upgrade their current systems, which adds to implementation timelines and costs.

5.4 Resistance to Technological Change

Adopting advanced technologies often encounters resistance from pharmacy owners, managers, and staff who may be hesitant to depart from established practices (Law et al., 2021). This resistance is frequently rooted in a lack of understanding of the benefits of AI and blockchain or concerns about the reliability of these systems. Furthermore, fear of job displacement due to automation can create additional opposition among staff, complicating efforts to implement new systems.

5.5 Training and Education of Pharmacy Staff

For technology-driven systems to function effectively, pharmacy staff must be adequately trained to operate and maintain them. This requires investment in education programs, which may involve hiring external trainers or sending staff for specialized training sessions (Hnatenko & Lysenko, 2024). However, balancing training requirements with daily pharmacy operations can be challenging, especially for pharmacies with limited staffing resources. Additionally, ongoing technological updates necessitate continuous learning, further stretching resources.

6. Impact of Secure Storage Practices

Secure storage practices play a pivotal role in preventing the diversion and misuse of controlled substances in community pharmacies. These practices, enhanced by technological innovations, strengthen the physical and procedural barriers to unauthorized access, ensuring compliance with regulatory requirements and promoting public health.

6.1 Significance of Tamper-Evident Systems

Tamper-evident systems are a cornerstone of secure storage practices. These systems incorporate physical safeguards, such as tamper-proof locks, seals, and digital access controls, to deter unauthorized entry and provide immediate indicators of breaches (Ching et al., 2023). Tamper-evident packaging and storage solutions also ensure accountability by making it clear when a container has been accessed, reducing the risk of unnoticed theft or diversion. Research has demonstrated that pharmacies using tamper-evident technologies experience fewer incidents of drug diversion compared to those relying solely on traditional security measures.

6.2 Evidence from Global Studies on Secure Storage Practices

Global studies have consistently highlighted the effectiveness of secure storage practices in mitigating risks associated with controlled substances. For instance, a study conducted in the United States found that pharmacies equipped with advanced storage systems, including automated safes and biometric access controls, decrease diversion incidents (Zheng et al., 2021). Similarly, research in the European Union demonstrated that secure storage combined with regular inventory checks significantly reduced the likelihood of theft and misuse of

controlled drugs (Kowalski & Esposito, 2023). These findings underscore the importance of adopting robust storage measures to safeguard pharmaceuticals.

6.3 Case Studies of Reduced Diversion Through Advanced Security Measures

Case studies further illustrate the transformative impact of advanced security measures on controlled substance storage. For example, a Canadian pharmacy chain implemented AI-powered safes that monitored access in real-time and flagged suspicious behaviour. As a result, the chain reported a 50% reduction in drug diversion incidents within the first year of adoption. In another instance, a European hospital pharmacy piloted the use of IoT-enabled smart cabinets for storing opioids (Zheng et al., 2021). These cabinets provided real-time alerts for unauthorized access and maintained detailed logs of drug retrievals. The initiative led to improved compliance with regulatory requirements and a noticeable decline in theft reports. These cases demonstrate that secure storage practices, when combined with advanced technologies, can significantly enhance the ability of pharmacies to prevent diversion and maintain the integrity of controlled substances.

7. Global Trends in Drug Diversion

Drug diversion remains a global concern, with varying trends observed between developed and developing countries. Understanding these trends is critical for implementing effective interventions and security measures in community pharmacies.

7.1 Drug Diversion in Developed vs. Developing Countries

In developed countries, drug diversion primarily involves prescription drugs, particularly opioids, benzodiazepines, and stimulants, which are often diverted through fraudulent prescriptions or theft from pharmacies. In the United States, the opioid crisis has highlighted the alarming prevalence of diversion, with opioids being the most frequently diverted controlled substance (Puac-Polanco et al., 2020). In 2018 alone, there were over 67,367 drug overdose deaths in the US, largely driven by opioids, many of which were obtained through diverted prescriptions (Wilson et al., 2020).

Conversely, in developing countries, such as Nigeria, the diversion of controlled substances is often linked to under-regulation, limited enforcement capacity, and inadequate pharmacy security. In these settings, diversion is commonly driven by the demand for pain relief medications, such as codeine and tramadol, which are frequently abused. Additionally, the unregulated sale of over-the-counter medicines further exacerbates the problem, contributing to a less controlled pharmaceutical environment (Okereke et al., 2021).

The contrast in drug diversion trends between developed and developing countries underscores the importance of adapting security measures to local contexts, accounting for factors such as regulatory strength, enforcement capabilities, and societal attitudes towards drug use.

7.2 Impact of Diversion on Public Health and Healthcare Systems

The impact of drug diversion is far-reaching, affecting both public health and healthcare systems. In developed countries, the diversion of opioids and other controlled substances has

contributed to the opioid epidemic, leading to a sharp increase in substance use disorders, overdose deaths, and criminal activities related to drug trafficking. The economic burden of opioid use disorder and fatal opioid overdose in the United States in 2017 was $1.02 trillion, with the majority due to reduced quality of life and life lost due to fatal opioid overdose (Florence et al., 2021). In 2018, 67,367 drug overdose deaths in the US involved an opioid, with synthetic opioid deaths increasing 10%, likely driven by illicitly manufactured Fentanyl (Wilson et al., 2020).

In Canada, the consequences of drug diversion are also severe, with the spread of Fentanyl contributing to a rising number of overdose deaths. A report that Fentanyl was the primary drug involved in 80% of opioid-related deaths in children under 10 years old in Ontario, Canada (Assen et al., 2023). Fentanyl was detected in 41% of fatalities without an active opioid prescription in Ontario, Canada, between 2013 and 2016, increasing to 47.5% in 2016 (Gomes et al., 2018). Furthermore, healthcare systems in both countries face resource strain due to increased demand for addiction treatment services, emergency care, and law enforcement efforts to address the diversion of controlled substances.

In Nigeria, the impact of drug diversion is exacerbated by the high prevalence of drug abuse and the strain on public health systems (Jatau et al., 2021). The misuse of opioids like tramadol and codeine has led to an increase in substance use disorders, particularly among youth. It has been associated with rising rates of violent crime as individuals seek to fund their drug habits (Onyima, 2023). Furthermore, healthcare resources are stretched thin as treatment facilities struggle to manage both the immediate health consequences of drug misuse and the long-term rehabilitation needs of affected individuals.

8. Regulatory Measures and Best Practices

Regulating controlled substances is crucial for maintaining public safety and ensuring that these drugs are used only for their intended medical purposes. Regulatory frameworks at both the national and international levels help prevent diversion, abuse, and illicit distribution. In this section, we discuss the regulatory measures, the role of regulatory bodies, emerging best practices, and case examples of effective regulation in controlling the misuse of controlled substances.

8.1 National and International Regulations

National regulations govern the production, distribution, and use of controlled substances within a specific country. In contrast, international regulations aim to coordinate efforts across borders to prevent the trafficking and diversion of these substances.

In the United States, the Controlled Substances Act (CSA) classifies drugs into five schedules based on their potential for abuse, risk of dependency, and accepted medical uses (Gabay, 2013). Schedule I substances, like heroin and LSD, are considered the most dangerous with no medical use. Schedule II drugs, such as opioids and stimulants, have a high abuse potential but are accepted for medical use under strict regulations. Schedule III substances, including anabolic steroids and ketamine, have a moderate potential for abuse and are medically prescribed. Schedule IV drugs, like benzodiazepines (for example, Valium and Xanax), have a lower abuse risk and are available with fewer restrictions. Schedule V substances, such as certain cough preparations, have the least potential for abuse and may be available with

minimal prescription requirements. This classification helps regulate drugs to balance medical needs and public health safety.

Similarly, in the European Union (EU), the European Medicines Agency (EMA) regulates controlled substances by ensuring drug quality, safety, and efficacy, while also addressing barriers to opioid access and preparing for new pharmacovigilance legislation to minimize misuse and abuse (Vranken et al., 2016). The EU also coordinates with member states to implement drug control measures through policies targeting pricing, prescribing patterns, and monitoring new psychoactive substances while also sharing information via systems like the early warning system for controlled substances (Varì et al., 2020).

Internationally, it plays a central role in regulating controlled substances by monitoring compliance with international drug control treaties. However, there are criticisms regarding its selective enforcement and the need for procedural changes (Hallam & Taylor, 2012). These regulations aim to strike a balance between ensuring the availability of controlled substances for legitimate medical use and preventing their misuse.

8.2 Role of Regulatory Bodies in Controlled Substance Security

Regulatory bodies play a critical role in the implementation of laws and regulations surrounding controlled substances. In Nigeria, for example, the National Agency for Food and Drug Administration and Control (NAFDAC) and the Pharmacy Council of Nigeria (PCN) are responsible for overseeing the distribution, prescription, and use of controlled substances. However, there is poor compliance with national guidelines for medication disposal, highlighting the need for improved management protocols (Itua et al., 2024; Olaniran, 2023). NAFDAC monitors the production and importation of these substances. At the same time, PCN ensures that pharmacies adhere to the legal and ethical standards for controlled substance handling.

Drug regulation in the US and UK has evolved differently, with the US historically adopting a more stringent regulatory approach that has shifted towards pragmatism. At the same time, the UK has maintained a relatively permissive regulatory culture with a focus on public health. However, both countries face challenges in effectively reducing drug-related harms (Abraham & Davis, 2020).

Regulatory bodies are tasked with setting guidelines for inventory management, monitoring prescription practices, conducting audits, and enforcing penalties for violations. Their role also extends to educating pharmacy personnel and the public about the risks of drug diversion promoting adherence to national and international laws.

8.3 Emerging Regulatory Standards and Best Practices

Emerging regulatory standards are being shaped by technological advancements, evolving healthcare needs, and changing patterns of drug abuse. Many countries are incorporating technology to improve drug control measures. In the US, prescription drug monitoring programs (PDMPs) are mandatory in many states, tracking the dispensing of controlled substances and helping identify issues like fraudulent prescriptions or excessive prescribing (Puac-Polanco et al., 2020). Similarly, Nigeria's NAFDAC has adopted electronic reporting and surveillance systems to enhance the monitoring and transparency of controlled substances (Olaniran et al., 2023). Alongside technological solutions, best practices emphasize continuous

education for pharmacy staff and the implementation of standard operating procedures (SOPs) to secure controlled substances. The World Health Organization (WHO) recommends that regular audits and risk assessments, along with staff education, are critical for identifying safety gaps and minimizing workplace violence in healthcare settings (Gostin et al., 2015).

9. Recent Advances in Technology for Controlled Substance Security

As drug diversion and misuse continue to present significant challenges to the pharmaceutical industry, new technological innovations are emerging to enhance the security of controlled substances in community pharmacies. These innovations leverage artificial intelligence (AI), real-time monitoring systems, blockchain technology, and the Internet of Things (IoT) to provide more efficient, reliable, and scalable solutions for drug security. In this section, we discuss the latest technological advances, their applications in pharmacy security, and case studies of their implementation.

9.1 Technological Innovations in Pharmacy Security

Technological advancements have revolutionized pharmacy security, moving beyond traditional methods like manual record-keeping and physical storage. Innovations such as AI-powered surveillance, automated inventory management, and integrated data systems are transforming how controlled substances are monitored, tracked, and secured. These technologies not only enhance security but also provide pharmacies with the ability to predict, prevent, and respond to security breaches in real time (Amingad et al., 2023). For example, AI-driven systems are now capable of monitoring prescription patterns and identifying anomalies, such as patients obtaining prescriptions from multiple sources or pharmacies dispensing excessive quantities of controlled substances. This predictive capability enables pharmacies to detect potential issues before they escalate, improving both compliance and security. Additionally, IoT-enabled smart storage solutions allow for the remote monitoring of controlled substances, ensuring that any unauthorized access triggers immediate alerts and real-time notifications to pharmacy staff or regulatory bodies.

9.2 AI-Driven Systems and Real-Time Monitoring

AI-driven systems have become increasingly integral in the real-time monitoring of controlled substances. These systems are capable of analyzing vast amounts of data from multiple sources, including prescription records, inventory systems, and surveillance cameras, to provide predictive insights into potential security threats. AI can identify patterns of abnormal behaviour, such as unusually high prescription frequencies or suspicious employee activities, allowing pharmacies to intervene proactively. Real-time monitoring is enhanced by AI-powered surveillance systems that use facial recognition and behavioural analysis to detect potential theft, diversion, or other security risks. These systems can track employees' and customers' movements within the pharmacy, alerting managers to suspicious activities. In addition, AI can be integrated with point-of-sale systems to monitor transactions and flag discrepancies, such as excessive quantities of controlled substances being dispensed. These real-time analytics help ensure immediate responses to security breaches, reducing the risk of theft and diversion (Jasmitha et al., 2023).

9.3 Blockchain and IoT Applications in Pharmacy Operations

Blockchain and IoT are playing an increasingly critical role in enhancing transparency, traceability, and accountability in pharmacy operations. Blockchain provides a secure and immutable record-keeping system that ensures the integrity of controlled substance transactions. Every step of the drug's journey, from production to distribution and dispensing, can be recorded in a blockchain ledger, preventing unauthorized changes or tampering with data. This immutable record-keeping is essential for pharmacies to comply with regulatory standards and provide an audit trail that regulatory authorities can easily review in case of discrepancies or suspicious activity. Blockchain also helps with monitoring the entire supply chain, from manufacturer to pharmacy, ensuring that controlled substances are not diverted or misused at any point along the way (Musamih et al., 2021).

IoT applications in pharmacy operations include the use of smart cabinets and safes that are equipped with sensors and alarms. These systems monitor the access and movement of controlled substances in real time, notifying pharmacy staff or security if unauthorized access occurs. IoT sensors can also track environmental conditions, such as temperature and humidity, to ensure the proper storage of controlled substances. Additionally, IoT-based inventory management systems can provide real-time stock levels and notify pharmacy managers if any discrepancies occur, such as missing drugs or expired inventory. This integration of IoT technology enhances security, improves operational efficiency, and ensures that controlled substances are stored under optimal conditions (Rathee et al., 2020).

9.4 Global Implementation and Case Studies

Advanced technologies are being implemented globally to enhance controlled substance security through collaboration between the public and private sectors. In the United States, AI-driven predictive analytics are used by pharmacy chains to monitor prescription dispensing and detect abnormal patterns, reducing fraud and "doctor shopping." AI-powered surveillance systems with facial recognition also help identify individuals with a history of drug abuse or diversion, improving regulatory compliance and reducing diversion rates.

In Europe, blockchain and IoT technologies are being integrated to improve pharmaceutical traceability. The European Union is exploring blockchain-based solutions to monitor controlled substance movements across the supply chain. A pilot program in the Netherlands used blockchain to track opioids, allowing real-time tracking and preventing diversion, with accurate, immutable records accessible to pharmacies and regulators.

In Nigeria, NAFDAC is adopting advanced technologies such as blockchain for drug traceability and IoT-enabled devices to monitor controlled substance inventories in real-time. These initiatives have shown promise in improving visibility and accountability, though challenges like infrastructure and technical capacity remain. Despite these obstacles, the advances signify a significant step toward enhancing controlled substance security in Nigerian pharmacies.

10. Discussions

The rapid evolution of technology has sparked significant improvements in the security and management of controlled substances in community pharmacies. From AI-driven surveillance

systems to blockchain-enabled transparency, these advancements are transforming how pharmacies address drug diversion, theft, and misuse. In this discussion, we explore the benefits of integrating AI and technology into pharmacy security, examine how combining traditional and advanced security measures can enhance protection, and consider the challenges faced by pharmacies in adopting these technologies. Finally, we look toward the future of controlled substance security in community pharmacies.

10.1 Benefits of AI and Technology in Enhancing Security

The incorporation of AI and technology into controlled substance security offers several key benefits, which are crucial in combating the growing issue of drug diversion. One of the main advantages is the ability to provide real-time monitoring and predictive analytics (Abbas et al., 2024). AI systems can analyze vast amounts of data from prescriptions, pharmacy operations, and surveillance footage to detect patterns of suspicious behaviour, such as prescription forgery or unusual purchasing trends (Vora et al., 2023). This predictive capacity helps pharmacies identify potential security threats before they escalate, enabling faster responses and preventing large-scale issues.

AI also enhances employee behaviour analytics, allowing pharmacies to monitor staff interactions with controlled substances. For example, AI systems can track the handling of drugs by pharmacy staff, identifying deviations from standard procedures that may indicate potential theft or diversion (Wong et al., 2023). Additionally, AI-powered surveillance systems equipped with facial recognition and behavioural analytics can enhance the security of physical spaces, helping to monitor both employees and customers and preventing unauthorized access to controlled substances (Amingad et al., 2023). These technologies significantly reduce human error, increase efficiency, and allow pharmacies to maintain higher levels of compliance with regulatory requirements.

Blockchain technology contributes to improving transparency and traceability in the drug supply chain (Shete et al., 2024). By providing an immutable, tamper-proof ledger, blockchain ensures that every movement of controlled substances can be tracked from manufacturer to pharmacy, providing a transparent audit trail. This visibility not only deters theft but also enables pharmacies to comply more easily with regulatory standards, reducing the risk of diversion and improving accountability.

10.2 Integration of Multiple Security Measures

While AI and technology offer substantial improvements to controlled substance security, the most effective approach combines these innovations with traditional security measures. Pharmacies should integrate advanced technologies with existing protocols like physical security systems (for example, locked cabinets and safes), manual audits, and staff training programs. This hybrid approach enhances overall security by addressing potential vulnerabilities across multiple fronts. For instance, AI-powered surveillance and predictive analytics can complement physical security measures like surveillance cameras and tamper-evident systems (Amingad et al., 2023). These systems can continuously monitor the premises for unusual behaviour while physical locks and safes secure the drugs themselves. Automated inventory management systems, paired with manual record-keeping and regular audits, ensure that any discrepancies in stock levels are quickly identified and rectified. Such an integrated security system not only addresses the complexities of modern drug diversion but also ensures that older, tried-and-tested methods remain in place to mitigate risks. Furthermore,

incorporating blockchain with pharmacy operations enables real-time tracking and tracing of controlled substances, providing greater transparency in drug movements. When combined with IoT devices, which monitor environmental conditions and drug storage access, blockchain enhances both the security and integrity of pharmaceuticals in community pharmacies (Shete et al., 2024).

10.3 Overcoming Challenges in Adoption

Despite the clear benefits of AI and technology, the adoption of these innovations in pharmacies faces several challenges. One of the major obstacles is the high initial cost of implementing these systems. While AI, blockchain, and IoT technologies offer long-term cost-saving benefits, the upfront investment in hardware, software, and staff training can be prohibitive, particularly for smaller pharmacies. In addition, pharmacies must ensure that they have the necessary infrastructure, such as reliable internet connectivity and adequate technical support, to implement and maintain these advanced systems fully.

Another challenge is the integration of new technologies with existing pharmacy management systems. Many pharmacies rely on legacy systems for inventory management and prescription processing, which may not be compatible with newer technologies like AI or blockchain. This can lead to integration issues and data incompatibility, complicating the adoption process.

Data privacy and compliance concerns are also significant barriers to the widespread adoption of AI and technology in pharmacy security. With the introduction of more advanced systems, pharmacies must ensure that they comply with data protection laws, such as the General Data Protection Regulation (GDPR) in the European Union and similar regulations in other regions. These regulations govern the handling of sensitive patient information and require pharmacies to implement robust cybersecurity measures to protect against data breaches and unauthorized access.

10.4 The Future of Controlled Substance Security in Pharmacies

Looking forward, the future of controlled substance security in pharmacies will likely be shaped by continued technological innovation. Advances in AI, blockchain, and IoT will lead to even more sophisticated systems for monitoring and securing controlled substances. As these technologies become more affordable and accessible, it is anticipated that smaller pharmacies will be able to adopt them as well, helping to standardize security practices across the industry.

One promising direction is the development of AI systems that not only monitor drug diversion but also predict and prevent potential security breaches before they occur. These systems could leverage machine learning algorithms to analyze patterns of behaviour over time, allowing for highly personalized, proactive security measures. Additionally, as blockchain technology continues to evolve, its applications in pharmacy security will likely expand, including the use of smart contracts to automate compliance with regulatory requirements and enforce transparency throughout the pharmaceutical supply chain.

Furthermore, the increased adoption of IoT technology will lead to the creation of smarter, more responsive security systems. For example, sensors embedded in drug storage units could alert staff when drugs are being accessed or when environmental conditions (such as temperature or humidity) deviate from acceptable ranges, providing real-time feedback on the storage conditions of controlled substances. In conclusion, the future of controlled substance

security in pharmacies lies in the effective integration of AI, blockchain, IoT, and traditional security measures. While challenges remain, the potential benefits of these technologies—ranging from enhanced security and transparency to better regulatory compliance—are immense. As the industry continues to evolve, embracing these innovations will be key to creating a safer and more efficient pharmaceutical ecosystem worldwide.

11. Conclusion

11.1 Summary of Findings

This review has explored the evolving landscape of controlled substance security in community pharmacies, particularly in Nigeria, where the adoption of advanced technologies is gaining traction. We examined the importance of securing controlled substances, the vulnerabilities associated with traditional security measures, and the significant role of AI, blockchain, and IoT in enhancing security.

Key findings include the following:

- **Drug Diversion Impact**: Drug diversion remains a critical concern, leading to public health challenges, including increased addiction rates, health risks, and economic costs. The growing sophistication of diversion tactics calls for innovative security solutions in pharmacies.
- **Technological Advancements**: AI, blockchain, and IoT technologies provide significant improvements over traditional security methods. AI-powered predictive analytics, blockchain for transparency, and IoT devices for real-time monitoring can enhance the accuracy and efficiency of controlled substance management.
- **Challenges in Adoption**: Despite the potential benefits, adopting these technologies presents challenges, including high costs, data privacy concerns, resistance to change, and integration with existing pharmacy systems. Addressing these barriers is critical for successful implementation.
- **Regulatory Measures**: National and international regulations provide a foundational framework for managing controlled substances. However, enforcement challenges persist, particularly in developing countries like Nigeria. Emerging regulations and best practices are shaping the future of pharmacy security.

11.2 Importance of Technology Adoption for Future Security

The importance of adopting advanced technology in pharmacy security cannot be overstated. Traditional security methods while foundational are increasingly inadequate in addressing the growing sophistication of drug diversion techniques. AI, blockchain, and IoT present transformative opportunities to enhance the accuracy, efficiency, and transparency of controlled substance security systems.

AI's predictive analytics can help prevent drug misuse and diversion by analyzing prescription data and employee behaviour. At the same time, blockchain ensures transparent, tamper-proof records of drug movements. IoT-enabled devices provide real-time monitoring of drug storage conditions and access, significantly reducing human error and improving compliance with regulatory standards. These technologies, when combined with existing security measures,

create a robust, multi-layered approach to controlling substance diversion and ensuring public health protection.

For future pharmacy security, embracing these technologies is crucial to keeping pace with the ever-evolving landscape of threats and ensuring the integrity of pharmaceutical supply chains. Technology adoption will play a central role in enhancing the effectiveness and efficiency of controlled substance management.

11.3 Call to Action for Stakeholders and Policymakers

The findings of this review highlight the urgent need for action from key stakeholders—pharmacy owners, healthcare providers, regulatory authorities, and policymakers—to embrace technological solutions for controlled substance security. Policymakers must support initiatives that promote the adoption of AI, blockchain, and IoT in community pharmacies. This support could include financial incentives, grants, and the development of industry standards to ensure that all pharmacies, regardless of size, can implement these technologies effectively.

Regulatory bodies like NAFDAC and the PCN must evolve their oversight practices to include the integration of advanced technologies. Clear guidelines and regulations that encourage the adoption of AI and blockchain in managing controlled substances will be essential to address existing gaps in enforcement and monitoring.

Moreover, pharmacies themselves need to invest in modern security systems and staff training to ensure they can fully leverage these technologies. Collaboration between the public and private sectors is vital to creating a secure, transparent, and efficient pharmacy ecosystem.

11.4 Recommendations for Future Research

Given the transformative potential of technology in pharmacy security, several areas require further investigation. Future research should focus on:

- **Longitudinal Studies on Technology Adoption**: Research into the long-term impacts of AI, blockchain, and IoT on controlled substance security in pharmacies would provide valuable insights into their effectiveness and sustainability.
- **Cost-Benefit Analysis**: Further studies that explore the economic implications of adopting these technologies, including cost savings, improved security, and reduced diversion rates, would be beneficial for decision-making in pharmacy operations.
- **Integration with Existing Systems**: Research into the practical challenges of integrating AI and blockchain systems with legacy pharmacy management systems is essential. This includes addressing interoperability issues and the training requirements for pharmacy staff.
- **Regulatory and Policy Research**: Studies examining the regulatory frameworks needed to support the adoption of advanced technologies in pharmacy security, particularly in developing countries like Nigeria, would provide a roadmap for policymakers.

In conclusion, while technological solutions to controlled substance security present a promising future, ongoing research and collaboration among stakeholders are essential for overcoming the current barriers to adoption and ensuring the widespread implementation of these technologies. The future of controlled substance security in community pharmacies lies

in the successful integration of AI, blockchain, IoT, and traditional security measures, which together can provide an effective defence against diversion, theft, and misuse.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Hassana Haruna Aliyu: Conceptualization, Literature search, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

Samuel Nkum Tenkorang: Supervision, Methodology, Critical revision, Validation, Writing – review & editing.

Hussaina Haruna Aliyu: Literature search, Data curation, Investigation, Writing – review & editing.

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Ethical Statements

This study is a review of existing literature and does not involve human participants, animals, or confidential patient data. Therefore, ethical approval was not required. The authors confirm that all sources cited in this manuscript have been appropriately acknowledged and referenced in accordance with academic standards.

Data and Code Availability

No data and code available for this study.

Supplementary Materials

No supplementary material for this study.

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