Check for updates

(REVIEW ARTICLE)

Barcode Technology in Healthcare Systems Enhancing Medication Safety Accuracy Efficiency and Error Reduction

Girish B J [1], Amit Tiwari [2, *], Mukesh Kumar Gupta [3] and Himanshu Vasnani [2]

[1] Department of Computer Science and Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.
[2] Department of Mechanical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.
[3] Department of Electrical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.

Abstract

Medication Dispensing causes serious issues resulting impacts to patient safety, overall financial cost and unintended consequences. Barcode Technology presents as a viable solution to overcome this problem. This review analyzes the benefits and challenges of barcode system usage in Pharmacy Settings. The important usage of Barcode Medication Administration (BCMA) leads to "five rights" of administration of medications and management of inventory so that the inventory levels and compliance are accurately managed. With the integration of wristbands and electronic health records, studies suggest that there is a reduction of 56% of medication errors. With barcode systems, processes get automated, manual documentation gets reduced, customer support calls get reduced thereby bringing efficiency into the system. In spite of technological advancements, technical issues, gaps in interoperability, human factors such as fatigue, staff resistance and pursuing shortcuts exist. Variations of compliance and merging electronic records create additional challenges. Technologies incorporating RFID, analytics and mobile device scanning have shown promises of better usage and scaling. The barcode technology presents a solution in patient safety and quality patient care. Organizations should take steps to foster barcode technologies in pharmacies. Upcoming research should study long term solutions, financial impacts and usage in constrained settings to realize the full potential of technology.

Keywords: Barcode Medication Administration (Bcma); Medication Safety; Pharmacy Informatics; Patient Safety; Healthcare Technology Integration

1. Introduction

Medication safety is the foundation of effective healthcare systems. Even though significant advances have been achieved in Health Care Systems, medication errors remain a prominent issue [1]. The error can occur at various stages such as prescription, transcribing, dispenses or monitoring. Usually, these errors could have been prevented. According to global health reports, errors in medications result in thousands or errors annually, some of which lead are detrimental, and some could even be fatal. The financial impacts result in cost in billions of dollars in preventable hospitalizations, prolonged stay and litigations. These issues pose an immediate need for strategies to reduce the issues and increase the safety of patients[2].

Technology has been employed as a tool to overcome challenges in accuracy, accountability and efficiency management. Barcode Technology has come out as an efficient system through Technological Advancements. Barcode systems come under Automatic Identification and Data Capture (AIDC). Barcode Technology has significantly changed the method for tracking and verifying medications under supply chain environment [3]. With Barcode Technology Medication information such as drug name, dosage strength, batch number and expiration date get encoded/barcoded. This enables

* Corresponding author: Amit Tiwari

machine readability thereby eliminating human errors. This method enables scaling up the systems, scanning medications for multiple patients and record keeping all done simultaneously[4].

Barcode Medication Administration (BCMA) is one of the technologies that is commonly used in health care systems. BCMA systems are structured to administer "five rights" of medication administration. The rights include, the right patient, the right drug, the right dose, the right route, and the right time. The process involves scanning the patient's identification band and the barcode of medication, which ensures that the right patient receives the right medication and eliminates wrong medication and wrong dosages. Studies indicate that hospitals with BCMA systems show a reduction in medication error[5]. Apart from hospitals, retail pharmacies also can take advantage of Barcode Technologies, thereby increasing customer satisfaction. By introducing the concept of automation, pharmacies can have sufficient stocks, avoid dispensing errors and can deliver the medications on time to complete the patient orders[6].

The changes to healthcare industry make the barcode adoption even more complex[7]. Regulatory requirements, patient expectations, and industry standards are constantly changing requiring constant updates to barcode system to ensure compliance[8]. The increase in personalized medicine and specialty pharmaceuticals makes it hard on labeling and tracking, as these products need to go through specialized protocols[9]. Data analytics and interoperability enforce barcode systems to seamlessly integrate with new systems and platforms, which require real-time reporting and predictive insights[10].

Radio Frequency Identification (RFID) has become an important component of Technology for providing the ability to track medications lacking direct line of sight tracking. Artificial Intelligence (AI) and machine learning algorithms have been studied to optimize inventories, prediction of shortages and identify patterns in reporting. Improvements in mobile technology and cloud-based systems are making barcode solutions scalable. These improvements are helping even the small-scale health care providers to benefit. With these innovations, even greater efficiency can be achieved in the space of Pharmacy Inventory Systems [11].

Benefits of barcoding systems provide greater efficiency even with the challenges of cost, integration and efforts to reduce medication errors[12]. Eliminating Integration Barriers and incorporating newer technologies, healthcare institutions can take advantage of barcode solutions to ensure safe, efficient and reliable medication management. The integration of barcode technology is a strategic investment in patient safety and quality care[13].

2. Literature Review

Table 1, summarizes prior studies investigating barcode, QR code, RFID, and blockchain technologies in healthcare, highlighting observations, applications, and outcomes related to patient safety, medication accuracy, data security, and workflow efficiency improvements.

Table 1 Comprehensive Review of Barcode, QR Code, RFID, and Blockchain Technologies Enhancing Healthcare Safety Efficiency

Ref.	Authors	Observations	Application	Remarks
1	Küng, K et al	The proposed approach involves generating a unique QR code for each patient's information, facilitating data transmission between nodes such as hospitals.	QR codes have become ubiquitous across several industries, including e-commerce, education, and healthcare. In the healthcare sector, QR codes are increasingly used to relay essential information regarding medical products, patient history, and healthcare education.	Overall, the proposed system can revolutionize data transmission and security in the healthcare sector, ensuring the safety and confidentiality of patient records.
2	Li, C. Y et al	Barcode Medication Administration integrates with workflows and provides	Barcode Medication Access Technology enhances medication safety by	Barcode Medication presents a viable alternative to reduce medication errors.

		immediate verification to reduce medication errors.	automating verification at the point of care.	
3	Joshi, P et al	The adoption of barcode scanners in medication administration has significant implications for clinical practice, primarily aimed at improving patient safety by ensuring that medications are administered accurately.	This review aims to assess the impact of BCMA on enhancing medication safety and healthcare efficiency.	The use of barcode scanners in medication administration offers several advantages, including a reduction in medication errors, enhanced patient safety, and a more streamlined medication administration process.
4	Heikkinen, I et al	The results of this review show that bar-coding technology may reduce medication errors in hospital settings, particularly preventing targeted wrong dose, wrong drug, wrong patient, unauthorized drug, and wrong route errors.	This systematic literature review is to examine the effectiveness of bar-coding technology on preventing medication errors and what types of medication errors may be prevented in the hospital setting.	All 10 studies showed overall positive effects associated with bar-coding implementation.
5	Kuitunen, S et al	Medication errors occur during the prescribing, distribution and administration of medication.	To identify that workarounds by nurses using information technology potentially compromises medication safety.	In particular, nurse workload and the patient–nurse ratio could be the focus for improvement measures as these are the most clearly modifiable factors identified in this study.
6	Reza, F et al	Ensuring the correct identification of the patient is key to matching the correct patients with the proper care.	This scoping review aims to find out what technologies based on unique patient identifiers are used to identify patients in healthcare facilities to increase patient safety and to identify future research trends.	Future research can focus on the combination of multiple technologies, including biometric methods, to improve identification and tools to support decisions about the use of technology in a particular context and health facility
7	Kubáňová et al	Colour-coded zones for rapidly dispensed medications are a simple, yet game-changing solution to improve the efficiency and safety of hospital pharmacy systems. This approach integrates visual ergonomics, staff training, and technology in solving some of the most common challenges in medication retrieval and general healthcare delivery.	An optimal pharmacy management system may involve a hybrid approach that integrates both visual and digital verification methods, ensuring both efficiency and patient safety across diverse healthcare settings.	This evidence-based system will go a long way in helping hospitals meet the ever-increasing demands.
8	Svensk, J et al	Pharmaceutical barcoding is creative electronics proposed at improving patient security	Barcoding supports photoelectric verification of cure presidency, improving	Pharmaceutical barcoding significantly reduces drug wrongs and unfavorable

		by underrating cure wrongs throughout healthcare arrangement.	transparency and accountability in healthcare practice.	drug occurrences, improving patient security in healthcare settings.
9	Mulac, A et al	To tackle these obstacles, this work is implementing a framework for the timely detection and anticipation of PCOS utilizing minimal yet promising clinical and metabolic indicators.	This framework endeavors to pinpoint crucial characteristics that could serve as preliminary indicators for PCOS, enabling a more streamlined and economically viable diagnostic process.	This work highlights the potential of machine learning techniques in improving the early detection and prediction of PCOS
10	Jadav, D et al	This study explores how technologies like barcoding and business intelligence assists in enhancing healthcare supply chain performance.	The vast amount of data captured through the barcoding and warehouse management system can be transformed into useful business insights using business intelligence dashboards that helps in decision-making and performance management.	The findings can serve as a guide for business managers in implementing effective barcoding systems and making best use of the data for business analytics in making effective decisions and enhance business performance.
11	Boehme, S et al	Barcode medication administration (BCMA) involves scanning a patient's unique barcode and medication barcodes to verify that these are correct before proceeding to administer a dose. It is becoming more common in many countries, often integrated with electronic prescribing and medication administration (ePMA) systems	Investigate the impact of Barcode Medical Administration on nursing activity and workflow.	Barcode medication administration (BCMA) is advocated as a technology that reduces medication errors relating to incorrect patient identity, drug or dose.
12	Bird, J	There exist intelligent technologies that are available for measuring medication adherence, including medication event monitoring system (MEMS®), smart blister packs, radio frequency identification (RFID) embedded smart drawers, and wisely aware RFID dosage (WARD) system.	Intelligent technologies can help in active monitoring of patients regarding adherence and are capable of eradicating various medication errors due to which adherence is affected.	Utilization of these advanced technologies and systems have aided in enhancing the adherence to a greater extent
13	Wahsheh, H. A et al	Smart technology becomes urgent in this field to prevent loss and keeps everything recorded, which means that you can have many details and graphs about each medicine through this system	The proposed smart fridge uses a barcode scanner that scans the expiry date products while keeping them in the refrigerator	This research aims to develop a system that can be added to most of the medical laboratories and pharmacies refrigerators available for medicine and

				products that have a barcode.
14	Abdul-Jabbar, S. S et al	This system enhances traceability, reduces redundancy, and supports data-driven decision-making in asset procurement and maintenance.	This study proposes a barcode-based medical asset management system designed to address persistent challenges in hospital asset tracking, integration, and condition monitoring. Using the Design Science Research (DSR) methodology, the system was developed and implemented in Bhayangkara Sartika Asih Hospital, Indonesia.	Given the widespread nature of similar challenges across healthcare institutions, this system has the potential to be adopted in various hospitals with minimal adjustments.
15	Essuman, A. A et al	Scanning a QR code on pharmaceutical packaging discloses essential information such as the medication's name, batch number, expiration date, and manufacturing date. This connectivity, together with blockchain technology, guarantees both accessibility and security of the data.	The objective is to provide an intuitive system that provides straightforward access to pharmaceutical information, facilitating informed decision-making in healthcare.	The incorporation of blockchain technology enhances the system's integrity by utilizing the hashing idea to guarantee data tamper resistance.
16	Tiu, M. G et al	A support plan must be developed for the cost of barcodes and RFID facility investments to expand barcode and RFID utilization in health care.	This study aimed to comprehensively examine the utilization status of barcodes and RFID in Korean hospitals, recognize the effects and obstacles associated with utilization, and explore the measures to expand the applications of barcodes and RFID.	Barcodes and radio frequency identification (RFID) are increasingly used in health care to improve patient safety.
17	Hutton, K et al	The major advantage of the combination between IoT technology and RFID is that the management of test box overall condition becomes much easier.	The main objective of this research work is to implement the RFID technology in Specimen collection in the healthcare sector and the IoT (Internet of Things) network supports the transaction while the specimen test box is being delivered.	This method is highly competent in identifying the location of medical devices in real-time and reduces the time-consuming of data logging than the barcode system.
18	van der Veen, W et al	This paper reported on a healthcare management system that operates in a decentralized way relying on blockchain technology, allowing individuals to (*i*) share personal health information, and (*ii*) know when they have been in close	This paper proposes CoviReader: a decentralized healthcare management system that shares user's data anonymously	The purpose of this short paper is to demonstrate a working prototype by which we assess and analyze strategies for mitigating the consequences of the COVID-19 health crisis in the US.

|				
		contact with an infected person while restricting public access to sensitive information.		
19	Svandova, K et al	The study showed that barcode scanning technology with handheld computer could help reduce medication errors, especially LASA drugs. Furthermore, this technology could improve efficacy and patient safety other than the use of barcode scanning system by pharmacist and barcode medication administration (BCMA) by nurse	To describe handheld computer improving pre-dispensing errors.	Handheld computer could reduce pre-dispensing errors caused by handling wrong drug, wrong dosage form and wrong strength of medicines as compared with those using traditional methods significantly
20	Jairoun, A. A et al	This comprehensive platform effectively handles treatment databases, tracking illness status, inpatient and outpatient records, and billing procedures for laboratory and pharmaceutical services.	There are several advantages to using blockchain, a safe decentralized record-keeping system, and QR codes, which can be scanned by smartphones. By putting patient data in an impenetrable blockchain, integrating these technologies improves patient data security.	By putting patient data in an impenetrable blockchain, integrating these technologies improves patient data security.
21	Malathi, P et al	Participants reported preference for scanning over other vaccine entry options and identified benefits of scanning.	Expanded use of 2D barcode scanning can meaningfully improve clinical practices by improving efficiency and staff satisfaction during vaccine data entry.	Small fonts on vaccine labels make manually recording vaccine data in patient records time-consuming and challenging.
22	Malathi, P et al	The initial goal was to utilize the Rover™ app on mobile devices to scan patients and medications. However, with in-room scanners and Workstation on Wheels still available, staff are not inclined to sign out a Rover™ phone unless they have patients in areas without built-in scanners (example hallways).	The global aim is to improve patient safety and Emergency Department staff efficiency in barcoding patients and medications using the Rover™ Mobile app.	The Emergency Department (ED) is one of the busiest areas in the hospital. Patients are often acute, and it can get chaotic at times. Such a complex environment requires an effective and efficient system to increase staff efficiency and elevate patient safety.
23	Barakat, S et al	The necessity of coordinating the latest advances in the capacity and exchange of therapeutic data constitutes one of the handful of	A full grade and successful alternative to storing information about patients and accelerating medical procedures. The effort	For the purpose of guaranteeing that medications get filled properly, the pharmacist module enables pharmacist

		participants of the two sides participating in the social claim over the best procedure for minimizing prices in the context of human care architecture.	focuses on the development and roll out of an efficient electronic health care card system, featuring modules involving admin, Superadmin, doctor, patient, chemist, laboratory, nurse, and receptionist.	accessibility to observe and check prescription. Through offering the ability to view health information, prescribing documentation, and therapeutic guidelines, the nurse's module helps alongside the treatment of patients.
24	Pal, P et al	This QR code serves as a unique identifier for the prescribed medicine, streamlining the retrieval process.	This innovative system seamlessly integrates modern technology to enhance patient outcomes and streamline the medication dispensing process.	The proposed automated drug dispenser leveraging QR code technology marks a significant leap forward in medication management, revolutionizing patient safety and convenience within the healthcare system.
25	Abd Elminam, D. S et al	By investing in this technology, healthcare providers can demonstrate their commitment to improving the quality of patient care.	The aim of the project is to examine the implementation of universal quick response (QR) codes issued by health insurance providers for patient identification within electronic health records (EHR).	The integration of QR codes into EHR using Fast Healthcare Interoperability Resources Application Programming Interface (FHIR API) can help standardize the identification process, making it more efficient and reducing medical errors.
26	Abd Elminam, D. S et al	QR codes provide portability in data storage and exchange. However, extreme care must be taken into consideration when using these two-dimensional code formats, particularly in healthcare applications.	The quantum-safe encryption algorithms, such as the Advanced Encryption Standard (AES) with a 256-bit key, are recommended to protect systems from the looming threat of quantum computing. This supports the use of QR Codes in healthcare applications without risking data and security breaches.	QR codes provide portability in data storage and exchange.
27	Chit, M. M. T et al	BCMA technology has the potential to decrease MAEs if adherence is high enough.	An updated BCMA technology contributes to a higher double check compliance and Medication Administration Error reduction, especially when changing an empty syringe.	An updated barcode medication administration (BCMA) technology on infusion pumps is implemented in the operating rooms to automate double check at a syringe exchange.
28	Cisneros, B et al	The research findings serve as a valuable resource for both academic circles and practical implementation, offering a foundation for further refinement of secure identification methods.	The main objective is to assess potential areas of application and the advantages of using QR code as a means of encoding biometric data.	The study underscores the importance of this integration in strengthening security measures, optimizing identification processes, and expanding the scope of application in various domains.

29	Sriboonruang, P et al	Barcode technology has been promoted as a potential solution to reduce the risk of misidentification (HSSIB, 2024). However, the focus on technology alone lacks the broader sociotechnical context within which barcode systems are used.	To enable any potential benefits, a barcode system should be considered as a sociotechnical innovation.	The success of any technology transformation programme hinges on understanding and addressing the intricate web of interactions between people, processes, and technology.
30	Pratap Singh, S et al	Focus on compliance by educating staff, evaluating processes, and using technology to streamline specimen management.	Real-time tracking improved chain-of-custody documentation and enhanced staff accountability, improving patient safety and clinical outcomes	Expand barcode tracking to additional procedural areas within the institution to enhance patient safety and improve operational efficiency across the healthcare system.
31	Pratap Singh, S et al	The barcodes encoded serialization data makes supply chain process harmonize in international trade where data readability through radio frequency devices become easier and more robust. The barcodes in serialization label also helps to mitigate the risk of counterfeiting as it contains unique product identifier.	Barcodes are integral part of pharmaceutical products which encoded with critical product attributes for tracking and tracing of product source.	The barcode should be placed carefully on the drug because any incorrect information may lead confusion and delay in supply chain and can cause of batch recall and further investigation
32	Kirit, I et al	The criticality of usage of QR code has been examined.	This research aimed to determine the applicability of utilizing barcode and QR code technology to improve construction and facilities management efficiency.	An investigation of the technological maturity to achieve this is presented, focusing on what their technological companies are capable of providing.
33	BV, S et al	This review aimed to fill this knowledge gap by synthesizing literature to determine the impact of Automated Dispensing Cabinets, Barcode Medication Administrator and closed-loop Electronic Medication Management Systems on clinical work processes, medication safety, and drug diversion associated with controlled medications in the inpatient setting.	Technology in the form of Automated Dispensing Cabinets (ADCs), Barcode Medication Administration (BCMA), and closed-loop Electronic Medication Management Systems (EMMS) are implemented in hospitals to assist with the supply, use and monitoring of medications.	More quality, targeted research is needed to provide evidence on the benefits and also risks of implementing technology to safeguard against inappropriate use of controlled medications in the inpatient setting.
34	Shanthini, E et al	Autonomy is associated with nursing satisfaction and quality of care. barcode medication administration organizes patient information	Using the case of barcode medication administration, our objective is to describe the challenges nurses face when informatics tools are not designed to	Information technology developers and healthcare organization managers should engage and better understand nursing work in order to develop

		and verifies medication administration.	accommodate the full complexity of their work.	technological and social systems to support it.
35	Goyal, A et al	Predictors of barcode scanning acceptance included perceived usefulness for patient care, perceived ease of use, and perceived usefulness (self).	Health policy changes have prompted hospital systems to assess implementation of implant barcode scanning systems to capture unique device identifiers.	Understanding nurse perceptions of new barcode scanning systems and engaging them in the implementation process are key areas for success and optimization of these systems.
36	Ang, R. J et al	Increasingly, regulation will drive the manufacturers to barcode their products, so many medical products will have barcode identification.	The value of barcode technology to ensure secure supply chains and the delivery of reliable and efficient processes in healthcare.	Barcode Technology required to ensure safety, possible recalls, and monitor surveillance, which has been important when there has been an occurrence of side effects with several vaccines
37	Hogerwaard, M et al	The use of QR code bracelets for postoperative congenital heart disease patients has shown high levels of satisfaction from families and providers, potentially reducing medical errors and treatment delays.	The study aimed to evaluate the feasibility of using QR code-enabled medical bracelets for congenital heart disease (CHD) patients after hospital discharge to ensure quick communication of vital information to other medical personnel in emergency situations.	The use of QR code bracelets for postoperative congenital heart disease patients has shown high levels of satisfaction from families and providers, potentially reducing medical errors and treatment delays.
38	Herlihey, T. A et al	The intervention involved cancer treatment education through a barcode scan method, with knowledge measured using a questionnaire. Data was analyzed using the Wilcoxon signed rank test, and SPSS software was used for statistical analysis.	This study evaluates the impact of cancer treatment education using barcode scan media on the knowledge of parents with children undergoing chemotherapy at Dr. Soetomo Hospital.	This method enhances understanding and management of chemotherapy side effects, leading to better childcare outcomes.
39	Fare, T et l	This study aimed to explore the barriers and enablers for the successful use of a Barcode medication administration system by examining the patterns of medication and patient scanning over time and potential safety implications.	Barcode medication administration systems may improve patient safety with successful integration and use.	BCMA systems may help to improve medication safety, but further research is needed to confirm sustained safety benefits.

## 3. Application of Barcode Technology in Pharmacy and Benefits

Barcode Technology is used extensively in hospital and retail pharmacy workflows. Using barcodes to store and transmit essential medication information reduces human error and increases the traceability of medications in the hospital and pharmacy workflows. In this section the applications of barcode technology in hospital and retail pharmacies are analyzed in the process highlight the role in patient safety and pharmacy processes. The following picture (Fig No.1) shows the number of publications reviewed year-wise.
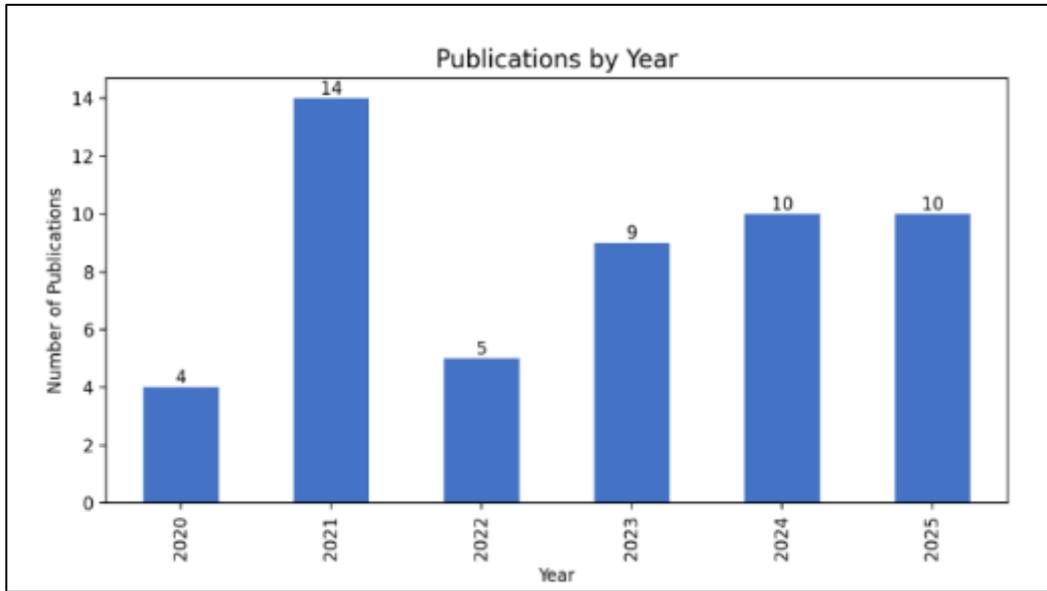
Figure 1 Graphic showing the Number of Publications reviewed year-wise

Medication Errors in Hospital environments have serious consequences. Barcode technology introduces automated verification and tracking mechanisms which enable clinical decision-making thereby reducing the risks of adverse events.

Barcode Medication Administration (BCMA) is one of the significant applications in hospital and healthcare sectors.
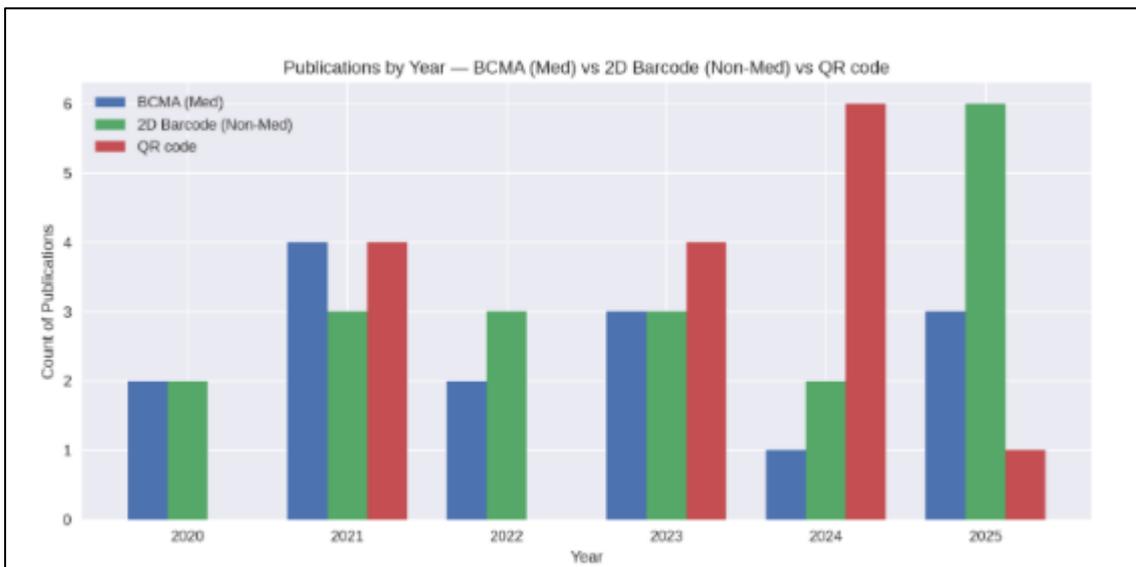

Figure 2 Graphic showing the Number of Publications per year Barcode Medical Administration(BCMA) versus 2D Barcode (Non-Med) versus QR code

The above graphic (Fig No.2) shows the distribution of publication year wise for BCMA, Two-dimensional and QR code.

BCMA systems are designed to enforce the "five rights" of medication administration: the right patient, the right medication, the right dose, the right time, and the right route. The following picture (Fig No.3) gives a graphical representation.

These principles form the basis of safe medication practices, and barcode scanning provides a practical approach for becoming compliant. In a general workflow, a nurse can scan the patient's wristband and the medication label prior to administering medicines. The system verifies this information with the electronic health record (EHR) to check accuracy. An alert gets generated if a discrepancy gets generated. As per the research published in clinical informatics journals, it indicates that the BCMA implementation reduces medication administration errors to a large extent.
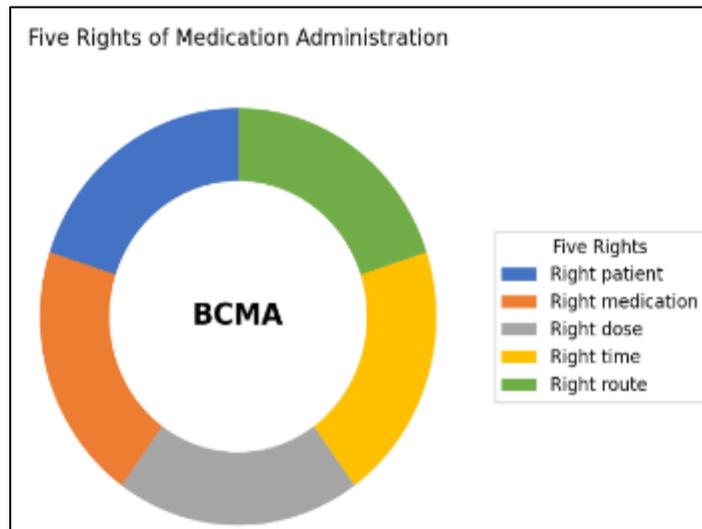
**Figure 3** Graphic depicting the Five Rights of Medication Administration

Managing optimum stock levels is very important for pharmacies as shortages and expiration of drugs can impact patient's health condition. Using Barcode systems recording medication batch numbers, expiration dates, and storage locations can be done in real time. Barcode systems enable tracking of medications as they are received, dispensed, or returned. Scanning barcode updates the inventory database automatically, which reduces manual entry and improves storage and tracking. With this functionality errors are reduced and accuracy and compliance with regulatory systems are achieved.

Patient Identification is yet another important application. In hospital systems patients get barcoded wrist bands which link to the patient's health records, which ensure that all the treatment gets accurately recorded. Combining BCMA, barcoded wristbands create a closed-loop system that checks patient identity at every point of care, to ensure overall accuracy and quality of service.

Retail pharmacies have different challenges such as large prescription volumes, immediate customer service needs and maintenance regulatory standards. Barcode technology plays a vital role in automating the process and keeping the system accurate and efficient.

Prescription Verification is one of the important aspects of retail pharmacies. Dispensing wrong medications, sending incorrect dosage can have serious consequences. Barcode scanning ensures the matching of right medication with right prescription. When discrepancies show up, the pharmacist gets alerted to correct the problem.

Barcode Technology ensures traceability, which is a mandatory requirement for regulatory compliance and management of recalled medications. If a recall gets triggered then the pharmacy can expedite the corrective actions, notify the customers, and reduce the health risks and legal liabilities. The following graphic (Fig No.4) compares Key Telepharmacy Applications and the associated benefits.
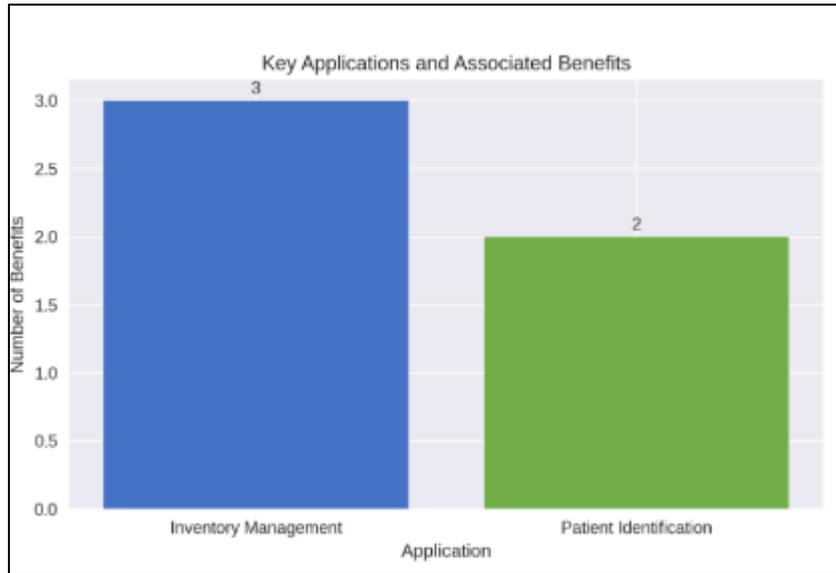
Figure 4 Comparison of Key Telepharmacy Applications and Their Associated Benefits

Retail Pharmacies, similar to hospitals, should maintain accurate inventory levels and track expired medication levels to avoid financial losses. Barcode system automates the process of receiving, dispensing, returns, stock outs and expiration management. With advanced barcode system management, expiry . These features enhance the overall efficiency of the retail pharmacy.

The advantages of barcode systems address areas such as error reduction, barcode reduction, elimination of error prone manual activities so that pharmacists can focus their attention on patient health care. The audit trails for compliance with regulatory standards such as those set by the Food and Drug Administration (FDA) and other agencies can be accomplished effectively. Barcode systems enable data collection which can be used as a valuable tool for analyzing risks, pattern generation and overall analytics study. The following picture (Fig No.5) compares hospital technology benefits in Hospital and Retail Pharmacy Settings.
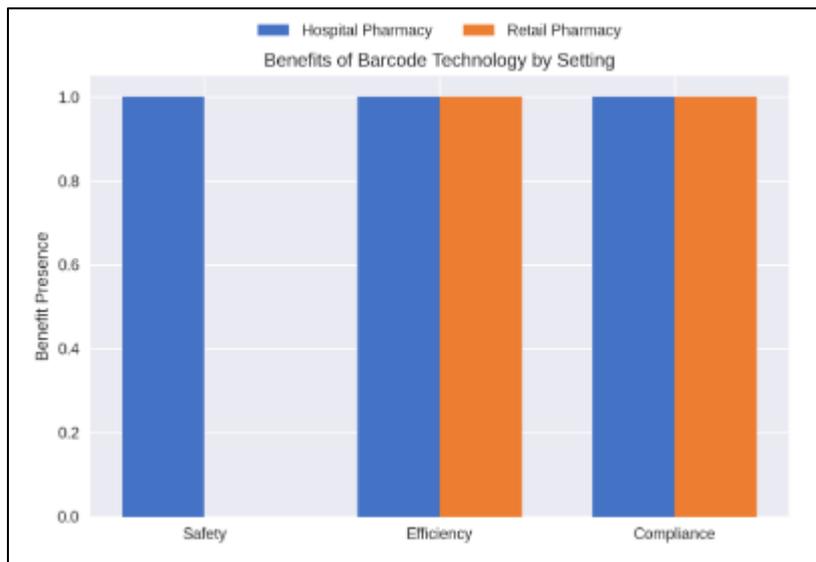

Figure 5 Comparison of Barcode Technology Benefits in Hospital and Retail Pharmacy Settings

4. Key Findings

Research on the usage of barcodes in pharmacy emphasizes the role in improving medication safety and operational efficiency. Barcode Medication Administration (BCMA) systems have indicated decrease in errors by following the "five

rights" of medication administration: the right patient, drug, dose, time, and route. Studies indicate reduction error rates from 23% to 56%, which means lesser adverse drug events and improved patient outcomes. This improvement is due to automated verification process when healthcare professionals scan patient identification barcode and medication label prior to administering the medication.

A common error is due to barcode wristbands and electronic health records disconnected. By linking the two a closed-loop system gets created which verifies patient identity throughout the healthcare workflow. Research also indicates that compliance with barcode scanning protocols improves when mobile devices such as tablets and smartphones are used instead of stationary scanners. As an example, emergency departments using mobile solutions reached compliance rates of 96.8%, compared to 85.1% having desktop systems. This shows the importance of ease-of-use technology in complying with standards. The following picture (Fig No.6) shows the compliance rates of barcode scanning device by types – Mobile Devices and Desktop Systems.
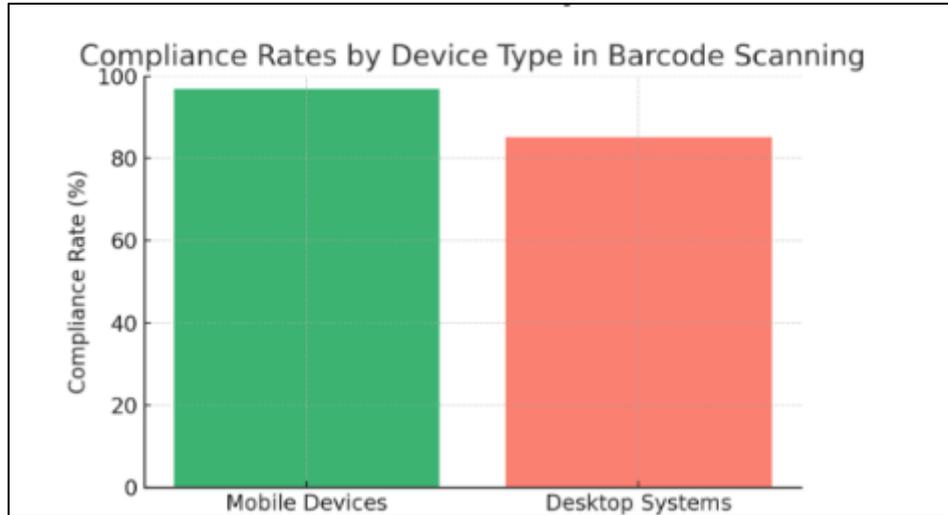
Figure 6 Compliance Rates for Barcode Scanning by Type of Device: Mobile versus Desktop Systems

Barcode systems minimize manual entry errors when used for automating documentation . Traceability enhances recall management which enables the process to be compliant with regulatory compliance . Having good recall management, the pharmacies can remove the recalled medication, which avoids the health risks and legal risks. The research also points to a number of challenges to implement barcode systems. Unreadable barcodes, unscannable barcodes, malfunctioning scanners pose technical challenges. Staff resistance and the need for workarounds pose some of the human challenges. Huge variance in adaptation for barcode systems across various samples range from 5.6% to 67%. This suggests the need for organizations to play important roles in adopting the barcoding systems.

Studies indicate that the training programs are necessary to follow the protocols, and system design improvements to reduce workarounds. Advanced technologies such as Radio Frequency Identification (RFID) and artificial intelligence (AI) play a very important role in inventory optimization and safe medication dispensing. Research indicates, barcode Technology enhance supply chain securities, enable global safety policies and transparency in pharmacies, especially in post COVID era.

5. Limitations and Gaps

Inconsistent and low adherence to barcode scanning protocols comes out as one of the limitations. Studies indicate that scanning rates for medication scans and patient scans vary significantly across under different settings. The ranges for medication scans vary from 5.6% to as high as 67%. The ranges for patient identification scans vary from 4.6% to 89%. Compliance often declines over time without reinforcement, which limits the long-term impact of barcode systems on medication safety.

Technical and workflow barriers make the implementation complicated. Technical Problems include unreadable barcodes, malfunctioning scanners, poor label quality, curved surfaces create disruption in workflows. These issues make the system vulnerable and force the staff to resort to workarounds. Generally, nurses and pharmacists think that the use of barcode technology would be time consuming while doing the medication rounds which causes

inconsistencies in usage. The following picture (Fig No.7) indicates common barriers to successful barcode implementation in Pharmacy Settings.
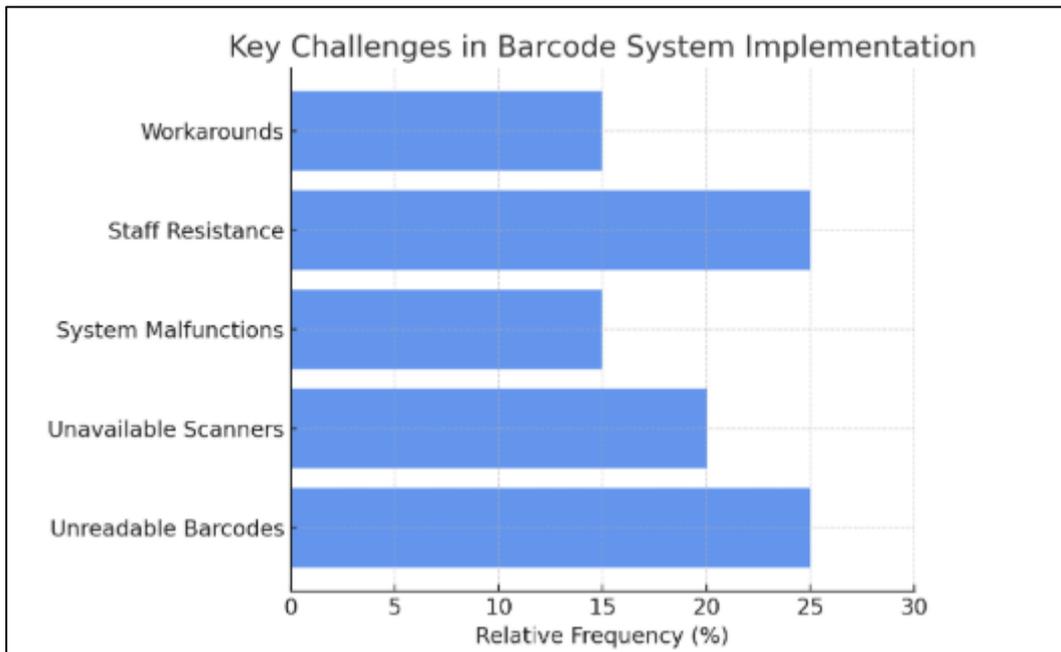
Figure 7 Common Challenges for Implementing Barcode Systems in Pharmacy Settings

Challenges in integration exist. Integration with electronic health records (EHRs) and automated dispensing systems create integration challenges. This results in inefficiencies and limiting scalability. Interoperability between systems poses another challenge. Various vendors and their platforms in large hospital IT systems make interoperability hard to achieve. Studies on short term benefits indicate reduction in medication errors, however the evidence for long term benefits with barcode technology and patient safety is yet to be established. Most of the research has been conducted in high income countries which has left research gaps as to how the barcode technologies are impacting low-income countries with limited resources.

To summarize, barcode technology offers significant advantages for medication safety and operational efficiency. However, effectiveness has been limited by compliance variations, technical challenges, interoperability and integration challenges, human considerations, and gaps in evidence for long term usage. To address these limitations robust technical solutions, workflow modifications, constant training, are necessary to ensure effective and efficient use.

6. Conclusion

Barcode technology has emerged to be a powerful solution in minimizing medication errors and enhancing operational efficiency in hospital and pharmacy environments. It is built on the principles to adhere to the "five rights" of medication administration and enhance patient identification through closed-loop systems emphasizes its role in medication safety management. Barcode systems ensure error prevention. Barcode systems fine tune inventory management, strengthen compliance for regulatory standards, and ensure faster elimination of recalled products, thereby contributing to overall cause of healthcare quality. Although barcode systems offer significant advantages, they come with challenges. Barcode technology has technical limitations such as unreadable barcodes, scanner malfunctions, integration and interoperability issues. Limitations under human factors include resistance of use and application of workarounds. These challenges hinder optimal utilization. Robust technical approach, rigorous training and continuous improvements are needed to address the above challenges. Emerging technologies, such as RFID, AI, and mobile applications, offer significant potential for future enhancement for barcode systems. Research in low earning settings would be necessary for global adoption. Barcode technology can prove to be the foundation of patient safety and foster digital transformation in healthcare. By adopting innovations and with organizational support, healthcare systems can benefit from barcode technology, to ensure safe and efficient patient care.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1]   Küng, K., Aeschbacher, K., Rütsche, A., Goette, J., Zürcher, S., Schmidli, J., & Schwendimann, R. (2021). Effect of barcode technology on medication preparation safety: a quasi-experimental study. International journal for quality in health care, 33(1), mzab043.

[2]   Li, C. Y., Huang, M. H., Lin, Y. S., Chu, C. M., & Pan, H. H. (2024). Effects of Implementing a Barcode Information Management System on Operating Room Staff: Comparative Study. *Journal of Medical Internet Research*, *26*, e56192.

[3]   Joshi, P., & Sawant, S. (2024, September). The impact and potential of quick response (QR) codes in healthcare: a comprehensive review. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 68, No. 1, pp. 1153-1158). Sage CA: Los Angeles, CA: SAGE Publications.

[4]   Heikkinen, I. (2022). Barcode medication administration and patient safety: A narrative literature review.

[5]   Kuitunen, S., Laakkonen, L., Janhunen, K., Kvarnström, K., & Linden-Lahti, C. (2023). Facilitators and Barriers Associated with the Use of Barcode Technologies in Drug Preparation and Administration in Hospital Settings— A Narrative Review of Qualitative Studies. *Journal of Patient Safety*, 10-1097.

[6]   Pandel, N., Tiwari, A., Bansal, P., & Amrousse, R. (2025). Unlocking the Potential of AI in Healthcare: A Critical Review of Innovations Barriers and the Path Forward. *Integrating AI With Haptic Systems for Smarter Healthcare Solutions*, 467-492.

[7]   Kubáňová, Jaroslava, Iveta Kubasáková, Kristián Čulík, and Lukáš Štítik. "Implementation of barcode technology to logistics processes of a company." *Sustainability* 14, no. 2 (2022): 790.

[8]   Svensk, J., & McIntyre, S. E. (2021). Using QR code technology to reduce self-administered medication errors. *Journal of pharmacy practice*, *34*(4), 587-591.

[9]   Mulac, A., Mathiesen, L., Taxis, K., & Granås, A. G. (2021). Barcode medication administration technology use in hospital practice: a mixed-methods observational study of policy deviations. *BMJ quality & safety*, *30*(12), 1021-1030.

[10]   Jadav, D., Patel, D., Gupta, R., Jadav, N. K., & Tanwar, S. (2022, May). BaRCODe: A blockchain-based framework for remote COVID detection for healthcare 5.0. In *2022 IEEE International Conference on Communications Workshops (ICC Workshops)* (pp. 782-787). IEEE.

[11]   Boehme, S., Wohlt, P., Valentine, J., & Ensign, R. (2022). Sustained barcode medication administration rates less than 2 percent in a large healthcare system. *Journal of patient safety and risk management*, *27*(6), 268-274.

[12]   Bird, J. (2024). Using change management to implement barcode medicines administration technology. *Nursing Management*, *31*(5).

[13]   Wahsheh, H. A., & Al-Zahrani, M. S. (2021, May). Secure and usable QR codes for healthcare systems: the case of covid-19 pandemic. In *2021 12th international conference on information and communication systems (ICICS)* (pp. 324-329). IEEE.

[14]   Abdul-Jabbar, S. S. (2023). Secure QR-code generation in healthcare. *Karbala International Journal of Modern Science*, *9*(2), 14.

[15]   Essuman, A. A., & Green, A. (2025). The Promise of Barcode Medication Administration for Enhancing Medication Safety in Low-Resource Settings. *Quality Management in Healthcare*, *34*(4), 335-336.

[16]   Tiu, M. G., Ballarta, P. J., De Leon, K. A., Isulat, T., Narvaez, R. A., & Salas, M. (2025). Impact on use of barcode scanners in medication administration: An integrative review. *Canadian Journal of Nursing Informatics*, *20*(1).

[17]   Hutton, K., Ding, Q., & Wellman, G. (2021). The effects of bar-coding technology on medication errors: a systematic literature review. Journal of Patient Safety, 17(3), e192-e206.

[18] van der Veen, W., Taxis, K., Wouters, H., Vermeulen, H., Bates, D. W., van den Bemt, P. M., ... & Mangelaars, I. (2020). Factors associated with workarounds in barcode-assisted medication administration in hospitals. *Journal of Clinical Nursing*, *29*(13-14), 2239-2250.

[19] Svandova, K., & Smutny, Z. (2024). What Technologies Based on Unique Patient Identifiers Are Used for Patient Identification in Healthcare?. *Digital Health and Informatics Innovations for Sustainable Health Care Systems*, 1264-1268.

[20] Jairoun, A. A., Al-Hemyari, S. S., Shahwan, M., El-Dahiyat, F., & Al-Ghananeem, A. M. (2025). Improving efficiency in hospital pharmacy systems: the case for color-coded zones for rapidly dispensed medications. Journal of Pharmaceutical Policy and Practice, 18(1), 2493169.

[21] Malathi, P., Sai, B. C., Sahithi, B., Sravani, K. V., & Vamsi, P. T. (2024, July). Blockchain-Driven Healthcare Management: A Secure and Efficient Prescription System with OCR and QR Code. In *International Conference on Emerging Research in Computing, Information, Communication and Applications* (pp. 77-88). Singapore: Springer Nature Singapore.

[22] Zingde, S., & Shroff, N. (2021). Enhancing healthcare supply chain performance through barcoding and business intelligence. *International Journal for Research in Engineering Application & Management (IJREAM)*, *6*(12), 2454-9150.

[23] Barakat, S., & Franklin, B. D. (2020). An evaluation of the impact of barcode patient and medication scanning on nursing workflow at a UK teaching hospital. *Pharmacy*, *8*(3), 148.

[24] Pal, P., Sambhakar, S., Dave, V., Paliwal, S. K., Paliwal, S., Sharma, M., ... & Dhama, N. (2021). A review on emerging smart technological innovations in healthcare sector for increasing patient's medication adherence. *Global Health Journal*, *5*(4), 183-189.

[25] Abd Elminam, D. S., Taha, M., & Nabil, A. (2020). Improving healthCare using smart medical refrigerator barcode reader system. *IJCSNS*, *20*(10), 1.

[26] Mahmudah, N. A., Shin, H. G., Ock, M., Jo, A. J., Min, A., Pyo, J., ... & Kim, S. (2023). Barcode and radio frequency identification utilization varied across Korean hospitals. *International Journal for Quality in Health Care*, *35*(3), mzad063.

[27] Chit, M. M. T., Srisiri, W., Siritantikorn, A., Kongruttanachok, N., & Benjapolakul, W. (2021, December). Application of RFID and IoT technology into specimen logistic system in the healthcare sector. In *2021 3rd International Conference on Advancements in Computing (ICAC)* (pp. 7-12). IEEE.

[28] Cisneros, B., Ye, J., Park, C. H., & Kim, Y. (2021, January). CoviReader: using IOTA and QR code technology to control epidemic diseases across the us. In *2021 IEEE 11th annual computing and communication workshop and conference (CCWC)* (pp. 0610-0618). IEEE.

[29] Sriboonruang, P., & Rattanamahattana, M. (2023). Barcode scanning technology to improve pre-dispensing errors. *Greater Mekong Subregion Medical Journal*, *3*(1), 7-12.

[30] Pratap Singh, S., Porwal, S., Agarwal, A., Deval, V., & Kaushik, I. (2024, May). Enhancing Patient Access and Security: Blockchain-QR Integrated Hospital on Tap System. In *International Conference on Recent Developments in Cyber Security* (pp. 49-62). Singapore: Springer Nature Singapore.

[31] Evanson, H. V., Reed, J. H., Cox, R., Clinthorne, A. D., Williams, W. W., Vallero, J., ... & Gerlach, K. (2021). Improving staff experience with vaccine data entry with 2D barcode scanning. *Journal of Nursing Care Quality*, *36*(2), 143-148.

[32] Kirit, I. (2023). Improving Patient Safety and Emergency Department Staff Efficiency in Barcode Medication Administration by Using the Rover™ Mobile Application.

[33] BV, S., Kalaskar, R., Tupkar, T., Bhalerao, A., & Angadi, S. (2023, June). A System on E-Health Care Card Using QR Code. In *Proceedings of the 5th International Conference on Communication and Information Processing (ICCIP)-2023*.

[34] Shanthini, E., Subasri, A., Yagavi, T., & Vinodhini, M. (2024, July). QR-Code Automated Drug Dispenser. In *2024 2nd International Conference on Sustainable Computing and Smart Systems (ICSCSS)* (pp. 224-230). IEEE.

[35] Goyal, A. (2023). Transforming Patient Check-in/Registration with a Fast Healthcare Interoperability Resources (FHIR) Integrated QR Code System and Mobile App.

[36] Ang, R. J. (2021). Encrypted QR Code in Healthcare Applications. *Canadian Journal of Nursing Informatics*, *16*(2).

[37] Hogerwaard, M., Stolk, M., van Dijk, L., Faasse, M., Kalden, N., Hoeks, S. E., ... & Ter Horst, M. (2023). Implementation of barcode medication administration (BMCA) technology on infusion pumps in the operating rooms. *BMJ Open Quality*, *12*(2).

[38] Herlihey, T. A. (2025). 10 Beyond technology: a sociotechnical perspective on barcode systems for patient identification.

[39] Fare, T. (2025). Implementation of Barcode Tracking to Prevent Surgical Pathology Specimen Loss.