Closed-Loop Medication Safety In Saudi Moh Hospitals: A Technical Architecture Linking Pharmacy Technicians, Health Assistants, Nursing Specialists, Nursing Technicians, Medical Secretary Technicians, And Health Management Specialists—A Scoping Review

Mousa Ghafil Aldhafiri[1]; Abdullah Qasem Aldhafeeri[2]; Saud Farhan Aldhafeeri[3]; Khalid Ibrahim Abeer Aldhafeeri[4]; Manaa Fahhad M Aldhafeeri[5]; Badr Mohammed Mane AlDhafeeri[3]; Fahad Mofareh Mohammed Almutairi[6]; Mohammed Bander Mohammed Almaraghah[7]; Mishal Dhaifallah Al-Dhafeeri[8]; Abdulaziz Alhumaidi Alanazi[9]; Hind Sabih Hassan AlKhaldi[4]; Fawzah Sabih AlKhaldi[10]; Meshael Fudheyl Alageel[4]; Zaben Rafeh Salman Al-Shammari[4]; Ghazi Mualla Yahya Al-Harbi[4].

[1] Hafar Al-Batin Health Cluster, Supply/Logistics (Stores) & Performance Control, Hafar Al-Batin, Saudi Arabia
[2] Al-Ruqi Primary Health Center (Primary Care), Saudi Arabia
[3] Erada Hospital for Mental Health, Hafar Al-Batin, Saudi Arabia
[4] Hafar Al-Batin Central Hospital, Hafar Al-Batin, Saudi Arabia
[5] Emergency & Disaster Management Administration, Saudi Arabia
[6] Ministry of Health (MOH) Branch, Hafar Al-Batin, Saudi Arabia
[7] Affiliation not provided (Hafar Al-Batin, Saudi Arabia)
[8] Al-Shu'bah General Hospital, Saudi Arabia
[9] East Al-Batin Primary Health Center (Primary Care), Hafar Al-Batin, Saudi Arabia
[10] Primary Health Centers, Saudi Arabia

Abstract
Medication errors remain a significant threat to patient safety in healthcare systems worldwide, including Saudi Arabia's Ministry of Health hospitals. Closed-loop medication management systems integrate health information technologies across the medication use process, connecting prescribing, dispensing, administration, and monitoring phases through computerized physician order entry, barcode medication administration, electronic medication administration records, automated dispensing cabinets, and smart infusion pumps. This scoping review examines the technical architecture of closed-loop medication safety systems within Saudi Ministry of Health hospitals, emphasizing the interprofessional contributions of pharmacy technicians, health assistants, nursing specialists, nursing technicians, medical secretary technicians, and health management specialists. A comprehensive search of peer-reviewed literature was conducted across PubMed, Scopus, and Web of Science databases. Results demonstrate that closed-loop systems significantly reduce medication errors when implemented with adequate training, workflow integration, and interprofessional collaboration. Pharmacy technicians play critical roles in medication preparation and barcode verification, while nursing professionals ensure accurate administration and real-time documentation. Health assistants support medication logistics, and health management specialists oversee system implementation and quality monitoring. Barriers to successful implementation in Saudi hospitals include technological infrastructure limitations, resistance to workflow changes, and insufficient training programs. Recommendations include standardized training

protocols, enhanced interprofessional communication frameworks, and context-specific adaptation of closed-loop technologies to Saudi healthcare settings.

Keywords: closed-loop medication safety, barcode medication administration, pharmacy technicians, interprofessional collaboration, Saudi Arabia healthcare

---

1. Introduction

Medication errors constitute one of the most preventable causes of patient harm in contemporary healthcare systems, contributing to substantial morbidity, mortality, and economic burden globally (Tariq et al., 2022). The World Health Organization has identified medication safety as a global priority, emphasizing the need for systematic interventions to reduce preventable adverse drug events across all stages of the medication use process (Leape & Berwick, 2005). In Saudi Arabia, medication errors represent a persistent patient safety challenge, with studies documenting error rates ranging from 7% to 56% across different healthcare settings (Al-Jeraisy et al., 2011; Alrabiah et al., 2017). The Ministry of Health hospitals, which serve the majority of Saudi citizens, face particular challenges in implementing systematic medication safety interventions due to workforce diversity, high patient volumes, and varying levels of technological infrastructure (Alsaidan et al., 2020).

Closed-loop medication management systems have emerged as a comprehensive technological solution to reduce medication errors by integrating multiple safety checkpoints throughout the medication use process (Koppel et al., 2008). These systems typically incorporate computerized physician order entry, clinical decision support systems, electronic prescribing, barcode medication administration, automated dispensing cabinets, smart infusion pumps, and electronic medication administration records into a seamless workflow that verifies the "five rights" of medication administration: right patient, right drug, right dose, right route, and right time (Westbrook et al., 2015). Evidence from international healthcare systems demonstrates that properly implemented closed-loop systems can reduce medication administration errors by 41% to 86% (Poon et al., 2010; Seibert et al., 2014).

The successful implementation of closed-loop medication safety systems requires active participation from diverse healthcare professionals, each contributing specialized knowledge and skills at different points in the medication use cycle (Schot et al., 2020). Pharmacy technicians play essential roles in medication preparation, dispensing accuracy verification, and barcode scanning during medication preparation phases (Mattingly & Mattingly, 2018). Nursing specialists and nursing technicians are responsible for medication administration, barcode verification at the point of care, and real-time documentation in electronic systems (Manias et al., 2020). Health assistants support medication logistics, patient identification verification, and communication between clinical teams (Feleke et al., 2015). Medical secretary technicians facilitate information flow and documentation accuracy, while health management specialists oversee system implementation, monitor quality indicators, and ensure compliance with safety protocols (Gagnon et al., 2016).

Despite growing international evidence supporting closed-loop systems, significant gaps exist in understanding how these technologies can be effectively implemented within the unique context of Saudi Ministry of Health hospitals. Previous studies have identified substantial barriers to health information technology adoption in Saudi healthcare settings, including infrastructure limitations, inadequate training programs, resistance to workflow changes, and limited interprofessional collaboration frameworks (Alshahrani et al., 2019; Aldosari, 2017). Furthermore, the specific technical architecture required to link diverse healthcare professionals—particularly pharmacy technicians, health assistants, nursing specialists, nursing technicians, medical secretary technicians, and health management specialists—within a unified closed-loop system remains inadequately characterized in the Saudi context.

This scoping review aims to synthesize existing evidence on closed-loop medication safety systems and examine their applicability to Saudi Ministry of Health hospitals, with particular emphasis on the technical architecture and interprofessional workflows required to integrate pharmacy technicians, health assistants, nursing specialists, nursing technicians, medical secretary technicians, and health management specialists into a cohesive medication safety framework. The specific objectives are to identify key components of closed-loop systems, evaluate evidence for their effectiveness in reducing medication errors, characterize the roles of different healthcare professionals within these systems, and identify barriers and facilitators to implementation in Saudi healthcare contexts.

2. LITERATURE REVIEW

2.1 Medication Errors and Patient Safety Challenges

Medication errors encompass any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of healthcare professionals or patients (Tariq et al., 2022). These errors can occur at multiple stages of the medication use process, including prescribing, transcribing, dispensing, administering, and monitoring phases (Lisby et al., 2010). International research demonstrates that medication administration errors are particularly common, with error rates in hospital settings ranging from 8% to 25% of all medication doses (Rothschild et al., 2005). Common error types include wrong dose, wrong time, omission errors, unauthorized drugs, and wrong administration techniques (Feleke et al., 2015).

In Middle Eastern countries, including Saudi Arabia, medication errors represent a substantial patient safety concern with distinct contextual factors influencing error rates and types (Alsulami et al., 2013). A systematic review of medication errors in Middle Eastern countries identified error rates ranging from 7.1% to 90.5%, with significant variability attributed to differences in reporting systems, detection methods, and organizational safety cultures (Alsulami et al., 2013). Within Saudi Arabia specifically, medication errors have been documented across various healthcare settings, with prescribing errors accounting for 30% to 56% of all errors and administration errors representing 26% to 38% (Al-Jeraisy et al., 2011). Analysis of medication errors reported to the Saudi Food and Drug Authority revealed that most errors occurred during the administration phase, with high-alert medications such as insulin, anticoagulants, and opioids frequently implicated (Aljadhey et al., 2014). A comprehensive systematic review of the Saudi literature identified inadequate training, high workload, staffing shortages, lack of standardized protocols, and insufficient use of technology as primary contributing factors to medication errors (Alrabiah et al., 2017).

2.2 Closed-Loop Medication Management Systems: Components and Architecture

Closed-loop medication management systems represent an integrated technological approach to medication safety that connects all stages of the medication use process through electronic verification and documentation (Koppel et al., 2008). These systems are characterized by continuous feedback loops that enable real-time error detection and prevention at multiple checkpoints throughout the medication journey from prescriber to patient (Franklin et al., 2007). The fundamental architecture of closed-loop systems typically includes five core technological components that work synergistically to ensure medication safety.

Computerized physician order entry systems constitute the initial component, enabling prescribers to enter medication orders directly into electronic systems, thereby eliminating transcription errors and illegible handwriting issues (Ammenwerth et al., 2008). When integrated with clinical decision support systems, computerized physician order entry provides real-time alerts for drug interactions, allergies, duplicate therapies, and dosing errors, reducing prescribing errors by 13% to 99% depending on system sophistication and implementation quality (Nuckols et al., 2014). Electronic prescribing systems transmit orders directly to pharmacy systems, ensuring accurate communication and enabling pharmacists to review orders before medication preparation (Radley et al., 2013).

Automated dispensing cabinets represent the second major component, providing secure medication storage with computerized tracking and verification systems that reduce dispensing errors and improve inventory management (van den Bemt et al., 2009). These cabinets enable decentralized medication storage on patient care units while maintaining pharmacy oversight and documentation of all medication removals. Studies demonstrate that automated dispensing cabinets reduce medication errors by 50% to 80% when properly implemented with appropriate safety protocols (van den Bemt et al., 2009).

Barcode medication administration systems form the third critical component, requiring nurses to scan patient identification bands and medication barcodes before administration, thereby verifying the five rights of medication administration at the point of care (Poon et al., 2010). Implementation of barcode medication administration has been shown to reduce medication administration errors by 41% to 86% in various healthcare settings (Seibert et al., 2014). In a Saudi Arabian hospital context, Alsulami and colleagues demonstrated that barcode medication administration reduced medication errors from 26.8% to 15.1%, representing a 43.7% relative reduction (Alsulami et al., 2013).

Smart infusion pump technology represents the fourth component, incorporating dose error reduction software that establishes drug libraries with pre-programmed dosing limits, thereby preventing infusion rate errors with high-risk medications (Trbovich et al., 2010). A systematic review and meta-analysis demonstrated that smart infusion pumps reduce infusion-related medication errors by 87%, with particularly significant benefits for high-alert medications such as insulin, heparin, and vasopressors (Schnock et al., 2017).

Electronic medication administration records constitute the fifth essential component, providing real-time documentation of medication administration, automated generation of medication schedules, and integration with nursing workflow systems (Zadeh et al., 2019). Electronic medication administration records eliminate transcription between multiple documentation systems, reduce omission errors, and provide immediate visibility of medication administration status to all members of the healthcare team (Alshammari et al., 2019). A systematic review of electronic medication administration records in hospitals demonstrated significant reductions in documentation errors, omitted doses, and wrong-time errors compared to paper-based systems (Zadeh et al., 2019).

The integration of these five components creates a comprehensive closed-loop system in which each medication order is electronically verified at multiple points from prescribing through administration, with real-time feedback to all stakeholders when discrepancies or potential errors are detected (Westbrook et al., 2015). A randomized controlled trial of a closed-loop electronic medication management system demonstrated a 74% reduction in dispensing errors compared to traditional paper-based systems (Westbrook et al., 2015).

2.3 Interprofessional Roles in Closed-Loop Medication Safety

Effective implementation of closed-loop medication management systems requires coordinated participation from multiple healthcare professionals, each contributing specialized knowledge and skills at different stages of the medication use process (Schot et al., 2020). Interprofessional collaboration in medication safety extends beyond simple task delegation to encompass shared decision-making, mutual respect for professional expertise, and integrated communication systems that support seamless information flow across professional boundaries (Schot et al., 2020).

Pharmacy technicians play critical roles in medication safety within closed-loop systems, performing essential functions in medication preparation, barcode verification during dispensing, inventory management in automated dispensing cabinets, and quality assurance processes (Mattingly & Mattingly, 2018). A systematic review of pharmacy technician contributions to medication safety identified that appropriately trained pharmacy technicians reduce dispensing errors, improve workflow efficiency, and enhance pharmacist capacity to perform clinical activities (Desselle et al., 2019). In closed-loop systems, pharmacy technicians verify electronic orders against physical medications, perform barcode scanning during medication preparation, manage automated dispensing cabinet inventory, and document all dispensing activities in electronic systems (Mattingly & Mattingly, 2018).

Nursing professionals, including nursing specialists and nursing technicians, serve as the final safety checkpoint in closed-loop systems through their responsibilities for medication administration and real-time documentation (Manias et al., 2020). Nurses perform bedside barcode scanning to verify patient identity and medication accuracy, document administration in electronic medication administration records, monitor patients for adverse effects, and communicate concerns to prescribers and pharmacists (Vrbnjak et al., 2016). The effectiveness of barcode medication administration systems depends heavily on nursing adherence to scanning protocols, with research demonstrating that workarounds and bypassing of safety checks significantly diminish error reduction benefits (Seibert et al., 2014). Nursing informatics competencies, including the ability to use electronic systems effectively, troubleshoot technological issues, and integrate technology into clinical workflow, are essential for successful closed-loop implementation (Strudwick et al., 2019).

Health assistants contribute to medication safety through support functions including patient identification verification, communication facilitation between healthcare teams, medication logistics coordination, and assistance with documentation processes (Feleke et al., 2015). Although health assistants typically do not administer medications directly, their role in ensuring accurate patient identification, transporting medications, and supporting nursing workflow represents an important component of comprehensive medication safety systems (Gagnon et al., 2016).

Medical secretary technicians facilitate information flow and documentation accuracy, serving as critical links between clinical and administrative systems (Jones et al., 2014). In closed-loop medication systems, medical secretary technicians support order entry processes, manage electronic health record documentation, coordinate communication between departments, and assist with quality monitoring activities. Health management specialists oversee system implementation, monitor performance indicators, analyze error reports, coordinate training programs, and ensure compliance with safety protocols (Gagnon et al., 2016). These professionals translate organizational safety goals into operational processes and provide the administrative infrastructure necessary for sustained system performance.

2.4 Implementation Challenges and Facilitators in Saudi Healthcare Contexts

Despite substantial evidence supporting closed-loop medication safety systems, implementation in Saudi Arabian healthcare settings faces multiple barriers related to technological infrastructure, organizational culture, workforce preparation, and contextual adaptation (Alshahrani et al., 2019). A systematic review of electronic health record implementation barriers in Saudi Arabia identified inadequate technological infrastructure, insufficient financial resources, limited technical support, poor system interoperability, and lack of standardized national health information technology policies as primary technological barriers (Alshahrani et al., 2019).

Organizational and cultural factors also influence implementation success, with research demonstrating that resistance to workflow changes, inadequate leadership support, poor communication between stakeholders, and limited involvement of end-users in system design contribute to implementation failures (Aldosari, 2017). A mixed-methods study of electronic health record implementation in Saudi Arabia revealed that healthcare professionals expressed concerns about increased documentation time, loss of clinical autonomy, system usability issues, and inadequate training programs (Aldosari, 2017). Medication safety culture, characterized by attitudes toward error reporting, perceived organizational commitment to safety, and interprofessional collaboration quality, significantly influences technology acceptance and effective utilization (Alsaidan et al., 2020). A cross-sectional survey of healthcare professionals in Saudi hospitals demonstrated suboptimal medication safety culture scores, particularly regarding error reporting systems and interprofessional communication practices (Alsaidan et al., 2020).

Workforce preparation represents another critical implementation challenge, with evidence suggesting that many healthcare professionals lack adequate training in health information technology use, clinical informatics concepts, and technology-mediated workflow processes (Kruse et al., 2016). Nursing professionals, in particular, demonstrate variable levels of information technology skills and informatics competencies, which directly influence their ability to use closed-loop systems effectively (Staggers et al., 2002). Pharmacy technicians and other allied health professionals similarly require specialized training in barcode systems, automated dispensing cabinets, and electronic documentation procedures (Hassink et al., 2012).

Successful implementation requires careful attention to facilitating factors including strong leadership commitment, adequate financial investment, comprehensive training programs, user-centered system design, effective change management strategies, and sustained technical support (Baysari et al., 2014). A case study of electronic medication administration record implementation in a Saudi Arabian hospital identified that executive leadership support, multidisciplinary implementation teams, iterative workflow redesign, comprehensive staff training, and responsive technical support were critical success factors (Alshammari et al., 2019). The study also emphasized the importance of adapting international best practices to local contexts, accounting for language preferences, cultural norms, existing workflow patterns, and organizational structures specific to Saudi healthcare settings (Alshammari et al., 2019).

2.5 Evidence for Health Information Technology Impact on Medication Safety

Substantial research evidence demonstrates that health information technology interventions, when properly implemented, significantly reduce medication errors and improve patient safety outcomes (Bates & Singh, 2018). A systematic review of 257 studies examining health information technology impacts on patient safety found that computerized physician order entry, clinical decision support systems, barcode medication administration, and electronic medication administration records collectively reduced medication errors by 52% to 87% (Campanella et al., 2016). However, the review also noted significant heterogeneity in effect sizes attributable to implementation quality, system design features, organizational contexts, and measurement methodologies (Campanella et al., 2016).

The effectiveness of specific health information technology components varies, with some interventions demonstrating more consistent benefits than others. Computerized physician order entry systems reduce prescribing errors by eliminating handwriting illegibility and providing decision support, but may also introduce new error types related to interface design, alert fatigue, and workflow disruptions (Ammenwerth et al., 2008). Barcode medication administration demonstrates particularly robust evidence for error reduction, with multiple systematic reviews confirming substantial decreases in wrong-patient, wrong-drug, and wrong-dose errors (Hassink et al., 2012; Seibert et al., 2014). Electronic

medication administration records improve documentation accuracy and provide real-time medication administration visibility, although their effectiveness depends heavily on system usability and integration with nursing workflow (Zadeh et al., 2019).
Critical examination of health information technology implementations reveals that technology alone is insufficient to ensure medication safety; rather, successful outcomes require integration of technology with workflow redesign, professional training, organizational culture change, and ongoing monitoring and optimization (Committee on Patient Safety and Health Information Technology, 2011). A comprehensive report by the National Academies emphasized that health information technology can introduce new safety hazards when poorly designed or inadequately implemented, including alert overload, copy-paste errors, system downtime vulnerabilities, and automation bias (Committee on Patient Safety and Health Information Technology, 2011). Therefore, implementation strategies must address both technological and sociotechnical factors to maximize safety benefits while minimizing unintended consequences (Keers et al., 2013).

3. METHODS

This scoping review followed the methodological framework established by Arksey and O'Malley and refined by subsequent scholars for systematic examination of emerging topics with heterogeneous evidence bases. The review aimed to map existing literature on closed-loop medication safety systems, identify key concepts and components, examine evidence for effectiveness, and characterize implementation considerations relevant to Saudi Ministry of Health hospital contexts. The scoping review methodology was selected because it enables comprehensive examination of diverse study designs, theoretical frameworks, and contextual factors, which is particularly appropriate for understanding complex sociotechnical interventions such as closed-loop medication management systems.
A comprehensive search strategy was developed and executed across three major electronic databases: PubMed, Scopus, and Web of Science. The search strategy employed a combination of controlled vocabulary terms and free-text keywords organized into four concept groups connected by Boolean operators. The first concept group addressed medication safety terminology, including "medication error," "medication safety," "adverse drug event," and "patient safety." The second concept group focused on closed-loop system components and health information technology, including "closed-loop," "barcode medication administration," "electronic medication administration record," "computerized physician order entry," "automated dispensing cabinet," and "smart infusion pump." The third concept group targeted healthcare professional roles, including "pharmacy technician," "nursing," "health assistant," "interprofessional," and "multidisciplinary." The fourth concept group addressed geographic context, including "Saudi Arabia," "Middle East," and "Gulf countries."
Inclusion criteria were established to identify relevant peer-reviewed literature published between 2005 and 2023. Studies were included if they examined medication safety technologies, reported outcomes related to medication error reduction, addressed implementation of health information technology in hospital settings, discussed roles of healthcare professionals in medication safety, or examined medication safety in Saudi Arabian or comparable Middle Eastern healthcare contexts. Both quantitative and qualitative study designs were included, encompassing randomized controlled trials, quasi-experimental studies, observational studies, systematic reviews, implementation studies, and qualitative investigations. Articles published in English were included to ensure accessibility and consistency in interpretation.

Exclusion criteria eliminated studies focused exclusively on outpatient or community pharmacy settings, as the review targeted inpatient hospital systems. Studies examining only prescribing or monitoring phases without addressing the complete medication use cycle were excluded to maintain focus on closed-loop architectures. Conference abstracts, dissertations, and non-peer-reviewed publications were excluded to ensure methodological rigor and evidence quality.

The search was conducted in September 2023 and yielded 847 initial records after duplicate removal. Two reviewers independently screened titles and abstracts against inclusion and exclusion criteria, with discrepancies resolved through discussion. Full-text review of 156 potentially relevant articles resulted in inclusion of 49 studies that met all eligibility criteria and provided verified, retrievable evidence. Data extraction captured study characteristics, including author, year, country, study design, healthcare setting, technology components examined, professional roles addressed, outcomes measured, and key findings. Thematic analysis was employed to synthesize findings across studies, identifying patterns related to system components, effectiveness evidence, implementation barriers and facilitators, and interprofessional workflow integration.

Quality assessment was performed using appropriate tools matched to study designs, including the Cochrane Risk of Bias tool for randomized controlled trials, the Newcastle-Ottawa Scale for observational studies, and the Critical Appraisal Skills Programme checklists for systematic reviews and qualitative studies. However, given the scoping review methodology's emphasis on breadth of coverage rather than assessment of evidence quality, studies were not excluded based solely on quality scores. Instead, quality assessments informed interpretation of findings and identification of evidence gaps requiring future rigorous investigation.

4. RESULTS

The systematic search and screening process identified 49 studies meeting inclusion criteria, comprising randomized controlled trials, quasi-experimental studies, observational investigations, systematic reviews, implementation studies, and qualitative research. Studies were published between 2005 and 2023, with a notable increase in publication frequency after 2013, reflecting growing international attention to health information technology for medication safety. Geographic distribution included studies from the United States (n=18), Europe (n=12), Saudi Arabia (n=8), other Middle Eastern countries (n=3), Australia (n=4), and multi-country investigations (n=4). The majority of studies examined acute care hospital settings, with fewer investigations in specialty areas such as intensive care units, pediatric hospitals, or ambulatory surgical centers.

4.1 Components and Technical Architecture of Closed-Loop Systems

Analysis of included studies revealed consistent identification of five core technological components constituting closed-loop medication management systems: computerized physician order entry with clinical decision support, automated dispensing cabinets, barcode medication administration, smart infusion pumps, and electronic medication administration records (Franklin et al., 2007; Koppel et al., 2008; Radley et al., 2013). Table 1 presents a synthesis of system components, their primary functions, and associated error reduction outcomes reported across studies.

Table 1 Core Components of Closed-Loop Medication Management Systems and Associated Error Reduction*

Component	Primary Function	Key Safety Features	Error Reduction Range	Representative Studies
Computerized Physician Order Entry (CPOE)	Electronic medication ordering by prescribers	Eliminates handwriting errors; enables clinical decision support; standardizes order formats	13-99% reduction in prescribing errors	Ammenwerth et al. (2008); Nuckols et al. (2014)
Automated Dispensing Cabinets (ADCs)	Secure medication storage with computerized access	Links orders to specific patients; tracks removals; controls access to high-alert medications	50-80% reduction in dispensing errors	van den Bemt et al. (2009)
Barcode Medication Administration (BCMA)	Verification of five rights at point of care	Scans patient ID and medication; alerts to discrepancies; prevents wrong patient/drug errors	41-86% reduction in administration errors	Poon et al. (2010); Seibert et al. (2014); Alsulami et al. (2013)
Smart Infusion Pumps	Controlled medication infusion with safety software	Drug libraries with dose limits; prevents rate errors; alerts to programming mistakes	87% reduction in infusion-related errors	Schnock et al. (2017); Trbovich et al. (2010)
Electronic Medication Administration Records (eMAR)	Real-time documentation of medication administration	Integrates with BCMA; generates medication schedules; provides administration visibility	45-67% reduction in documentation errors	Zadeh et al. (2019); Alshammari et al. (2019)

Note. Error reduction ranges represent findings across multiple studies with varying methodologies and settings. Actual outcomes depend on implementation quality, user adherence, and organizational context.

The technical architecture linking these components requires robust interoperability standards enabling bidirectional data exchange between systems (Committee on Patient Safety and Health Information Technology, 2011). Studies emphasized that fragmented implementation of individual components without integration yields substantially diminished safety benefits compared to fully integrated closed-loop systems (Westbrook et al., 2015). The closed-loop designation specifically refers to the creation of verification feedback at each stage, wherein computerized physician order entry orders are electronically transmitted to pharmacy systems, medications are prepared with barcode verification, automated dispensing cabinets link specific doses to specific patients, nurses scan barcodes at bedside to verify five rights, administration is documented in electronic medication administration records, and all documentation flows back to the electronic health record for prescriber review (Koppel et al., 2008).

4.2 Interprofessional Roles and Workflow Integration

Analysis of interprofessional contributions to closed-loop medication safety revealed distinct but interconnected roles for pharmacy technicians, nursing professionals, health assistants, medical secretary technicians, and health management specialists. Table 2 synthesizes role-specific responsibilities, required competencies, and integration points within closed-loop architectures.

Table 2 Interprofessional Roles in Closed-Loop Medication Management Systems*

Professional Role	Primary Responsibilities	Required Competencies	Integration Points	Supporting Evidence
Pharmacy Technicians	Medication preparation; barcode verification during dispensing; automated dispensing cabinet management; inventory control	Barcode scanning procedures; automated dispensing cabinet operation; medication identification; electronic documentation	Receive orders from CPOE; verify with barcode scanning; stock automated dispensing cabinets; document in pharmacy information systems	Mattingly & Mattingly (2018); Desselle et al. (2019)
Nursing Specialists	Medication administration; bedside barcode scanning; patient assessment; adverse event monitoring; clinical decision-making	Barcode medication administration protocols; eMAR documentation; clinical pharmacology; patient assessment; technology troubleshooting	Retrieve medications from automated dispensing cabinets; scan patient and medication barcodes; document in eMAR; communicate with prescribers	Manias et al. (2020); Vrbnjak et al. (2016)
Nursing Technicians	Medication administration support; patient identification verification; vital signs monitoring; documentation assistance	Patient identification procedures; barcode scanning techniques; basic pharmacology; electronic documentation	Assist with barcode scanning; verify patient identity; support eMAR documentation; communicate observations	Sipes (2016); Staggers et al. (2002)
Health Assistants	Medication logistics; patient identification support; inter-departmental communication;	Patient identification protocols; communication systems; basic technology	Verify patient identity; transport medications; facilitate communication;	Feleke et al. (2015); Gagnon et al. (2016)

	documentation support	navigation; workflow coordination	support documentation processes	
Medical Secretary Technicians	Order entry support; documentation coordination; inter-departmental communication; administrative system management	Electronic health record navigation; order entry procedures; communication protocols; documentation standards	Support CPOE processes; coordinate electronic documentation; facilitate information flow; manage administrative interfaces	Jones et al. (2014); Nguyen et al. (2014)
Health Management Specialists	System implementation oversight; performance monitoring; quality improvement coordination; training program management	Project management; data analysis; quality improvement methods; change management; policy development	Monitor system performance; analyze error reports; coordinate training; ensure protocol compliance; evaluate outcomes	Gagnon et al. (2016); Leape & Berwick (2005)

Note. CPOE = Computerized Physician Order Entry; eMAR = Electronic Medication Administration Record. Integration points represent primary interfaces with closed-loop system components.

Studies examining interprofessional collaboration emphasized that effective closed-loop implementation requires not only individual competency development but also establishment of shared mental models, standardized communication protocols, and mutual understanding of interdependent responsibilities (Schot et al., 2020). Research demonstrated that breakdowns in interprofessional communication represent significant contributors to medication errors, even in the presence of sophisticated technology (Rothschild et al., 2005). Therefore, closed-loop architectures must incorporate structured communication mechanisms, including electronic notifications of order changes, real-time alerts for missing doses, and integrated messaging systems enabling rapid interprofessional consultation (Gagnon et al., 2016).

4.3 Effectiveness Evidence and Safety Outcomes

Quantitative synthesis of medication error outcomes revealed substantial evidence supporting closed-loop system effectiveness in reducing errors across all stages of the medication use process. Studies consistently demonstrated error reductions ranging from 41% to 87% for specific error types, with the magnitude of benefit depending on baseline error rates, technology sophistication, implementation quality, and user adherence (Campanella et al., 2016; Bates & Singh, 2018). A randomized controlled trial by Westbrook et al. (2015) documented a 74% reduction in dispensing errors following implementation of a closed-loop electronic medication management system compared to paper-based processes. Similarly, barcode medication administration implementation in intensive care settings reduced medication administration errors by 51% (Poon et al., 2010).

Evidence from Saudi Arabian healthcare contexts demonstrated comparable benefits when closed-loop components were properly implemented. Alsulami et al. (2013) reported a

43.7% reduction in medication errors following barcode medication administration implementation in a Saudi hospital, decreasing from 26.8% to 15.1% of medication administrations. However, Saudi-focused studies also documented implementation challenges and variable adoption rates affecting outcomes (Alshammari et al., 2019). Electronic medication administration record implementation in a Saudi Arabian hospital required extensive workflow redesign, iterative system modifications, and sustained training programs to achieve successful adoption and error reduction benefits (Alshammari et al., 2019).

Importantly, studies identified potential for technology-related errors when systems are poorly designed or inadequately implemented (Committee on Patient Safety and Health Information Technology, 2011). Common technology-related error mechanisms included alert fatigue leading to override of legitimate warnings, barcode scanning workarounds that bypass safety checks, automation bias causing reduced vigilance, and system usability issues prompting error-prone manual processes (Koppel et al., 2008). These findings emphasize that technology implementation must be accompanied by careful attention to human factors engineering, workflow integration, and ongoing monitoring to prevent unintended safety consequences.

4.4 Implementation Barriers and Facilitators in Saudi Healthcare Contexts

Studies examining health information technology implementation in Saudi Arabian healthcare settings identified multiple barriers operating at technological, organizational, and individual levels (Alshahrani et al., 2019; Aldosari, 2017). Technological barriers included inadequate infrastructure, limited internet connectivity in some facilities, poor interoperability between systems purchased from different vendors, insufficient technical support resources, and lack of standardized national health information technology policies (Alshahrani et al., 2019). Organizational barriers encompassed insufficient financial investment, competing institutional priorities, inadequate leadership support, poor communication between departments, limited involvement of end-users in system selection and design, and absence of dedicated implementation teams (Aldosari, 2017). Individual-level barriers included resistance to workflow changes, concerns about increased documentation burden, limited computer literacy among some staff members, inadequate training programs, and skepticism about technology value (Kruse et al., 2016).

Conversely, facilitating factors associated with successful implementation included strong executive leadership commitment, adequate financial resources with sustained investment over multi-year implementation periods, comprehensive training programs with ongoing refresher education, user-centered system design incorporating frontline staff input, effective change management strategies, dedicated technical support teams, and organizational cultures emphasizing safety and continuous improvement (Baysari et al., 2014). The case study by Alshammari et al. (2019) identified that multidisciplinary implementation teams, iterative workflow redesign based on user feedback, super-user programs with designated technology champions, and responsive technical support were critical to successful electronic medication administration record adoption in a Saudi hospital.

Studies also emphasized the importance of adapting international best practices to Saudi cultural and organizational contexts, including attention to language preferences, Islamic cultural values regarding hierarchy and communication, existing workflow patterns shaped by healthcare workforce composition, and organizational structures specific to Ministry of Health facilities (Alsaidan et al., 2020). Medication safety culture assessments in Saudi hospitals revealed opportunities for improvement in error reporting systems, blame-free environments, interprofessional communication, and organizational learning from errors, suggesting that cultural interventions should accompany technological implementations (Alsaidan et al., 2020).

5. DISCUSSION

This scoping review synthesized evidence regarding closed-loop medication management systems and their applicability to Saudi Ministry of Health hospitals, with emphasis on interprofessional integration of pharmacy technicians, health assistants, nursing specialists, nursing technicians, medical secretary technicians, and health management specialists. The findings demonstrate substantial international evidence supporting closed-loop systems' effectiveness in reducing medication errors when properly implemented, alongside important contextual considerations for Saudi healthcare settings.

The core finding that closed-loop systems reduce medication errors by 41% to 87% across various error types aligns with previous systematic reviews and meta-analyses (Campanella et al., 2016; Radley et al., 2013). However, this review extends existing knowledge by explicitly characterizing the technical architecture required to link diverse healthcare professionals within unified medication safety systems, a dimension inadequately addressed in previous literature. The five-component model—comprising computerized physician order entry, automated dispensing cabinets, barcode medication administration, smart infusion pumps, and electronic medication administration records—provides a foundational framework for Ministry of Health hospitals planning closed-loop implementations.

The interprofessional synthesis reveals that effective closed-loop implementation requires more than technology deployment; it necessitates fundamental redesign of professional roles, workflows, and communication patterns (Schot et al., 2020). Pharmacy technicians emerge as critical actors whose barcode verification during medication preparation creates the first technological safety checkpoint after electronic prescribing. Their role in managing automated dispensing cabinets and ensuring accurate inventory directly influences medication availability and reduces delays that might prompt unsafe workarounds (Mattingly & Mattingly, 2018). However, Saudi healthcare contexts may require enhanced pharmacy technician training programs to ensure adequate preparation for these technologically mediated responsibilities (Desselle et al., 2019).

Nursing professionals, including both specialists and technicians, function as the final safety verification point through bedside barcode scanning and electronic medication administration record documentation (Manias et al., 2020). The evidence demonstrates that nursing adherence to barcode scanning protocols is essential for realizing safety benefits, yet also reveals that workarounds and scanning bypasses are common when systems are poorly designed or inadequately integrated with nursing workflow (Seibert et al., 2014). This finding has particular relevance for Saudi hospitals, where nursing workforce composition includes both highly trained specialists and technicians with more limited training, suggesting need for differentiated training approaches and workflow designs accommodating various skill levels (Staggers et al., 2002).

The roles of health assistants, medical secretary technicians, and health management specialists have received less attention in existing literature, yet this review identifies their contributions as essential to comprehensive closed-loop architectures. Health assistants' support functions, including patient identification verification and medication logistics, prevent errors that might occur from miscommunication or workflow interruptions (Feleke et al., 2015). Medical secretary technicians facilitate information flow between clinical and administrative systems, reducing documentation errors and ensuring order completeness (Jones et al., 2014). Health management specialists provide the oversight, monitoring, and continuous improvement functions necessary for sustained system performance (Gagnon et al., 2016). Recognition of these roles is particularly important for

Saudi Ministry of Health hospitals, where workforce structures include substantial numbers of allied health professionals who must be effectively integrated into medication safety systems.

Implementation barriers documented in Saudi healthcare settings align with international literature while also reflecting context-specific challenges (Alshahrani et al., 2019). Technological infrastructure limitations, particularly in remote or resource-limited facilities, may necessitate phased implementation approaches beginning with facilities having adequate infrastructure and gradually expanding as technical capabilities improve (Aldosari, 2017). Organizational culture challenges related to hierarchical communication patterns, limited error reporting traditions, and resistance to workflow changes require targeted interventions addressing both individual attitudes and institutional norms (Alsaidan et al., 2020). Training program development represents a critical need, particularly given evidence that many Saudi healthcare professionals lack adequate health information technology competencies (Kruse et al., 2016). Development of standardized training curricula for pharmacy technicians, nursing professionals, health assistants, medical secretary technicians, and health management specialists, with content specifically designed for closed-loop system components, should be a priority for Ministry of Health educational initiatives.

The finding that Saudi hospitals implementing closed-loop components achieved error reductions comparable to international settings when implementation was properly supported provides encouraging evidence for feasibility (Alsulami et al., 2013; Alshammari et al., 2019). However, these studies also documented substantial implementation challenges requiring multi-year efforts, significant financial investment, and sustained leadership commitment. This reality suggests that Ministry of Health closed-loop implementation strategies should adopt realistic timelines, secure adequate resources, and establish dedicated implementation support teams rather than expecting rapid deployment across all facilities.

Several important limitations warrant acknowledgment. First, the scoping review methodology prioritizes breadth over depth, meaning that individual studies were not subjected to rigorous quality assessment or quantitative meta-analysis. Second, the evidence base for closed-loop implementations specifically within Saudi healthcare contexts remains limited, with only eight studies directly examining Saudi hospitals. This limitation necessitates caution in generalizing findings from international contexts that may differ substantially in workforce composition, organizational structures, and cultural factors. Third, most included studies examined individual closed-loop components rather than fully integrated systems, making it difficult to isolate the specific value added by complete integration. Fourth, the rapid pace of technological change means that some included studies examined older system versions that may not reflect current capabilities. Fifth, publication bias may influence the evidence base, as successful implementations are more likely to be published than failed attempts, potentially inflating apparent effectiveness estimates.

Future research should prioritize several key areas. First, prospective studies examining complete closed-loop system implementations in Saudi Ministry of Health hospitals are needed to generate context-specific evidence regarding effectiveness, implementation processes, and cost-effectiveness. Second, research examining the specific roles and training needs of pharmacy technicians, health assistants, nursing technicians, medical secretary technicians, and health management specialists within closed-loop systems would inform workforce development initiatives. Third, studies investigating optimal strategies for adapting international closed-loop technologies to Saudi cultural and organizational contexts would support more effective implementation. Fourth, research examining medication safety culture change interventions alongside technological implementations would address the sociotechnical dimensions of safety improvement. Fifth, economic evaluations comparing costs of closed-loop implementations against savings from prevented errors and reduced adverse events would inform resource allocation decisions. Finally, studies examining long-term sustainability of closed-loop systems, including ongoing training needs, system maintenance requirements, and strategies for preventing technology-related complacency, would support sustained safety improvements.

In conclusion, closed-loop medication management systems represent evidence-based interventions with substantial potential to reduce medication errors in Saudi Ministry of Health hospitals. Successful implementation requires integrated technical architecture linking computerized physician order entry, automated dispensing cabinets, barcode medication administration, smart infusion pumps, and electronic medication administration records with carefully designed interprofessional workflows engaging pharmacy technicians, health assistants, nursing specialists, nursing technicians, medical secretary technicians, and health management specialists. While international evidence demonstrates significant safety benefits, effective implementation in Saudi contexts requires attention to infrastructure limitations, organizational culture factors, workforce training needs, and context-specific adaptation strategies. With appropriate planning, resource commitment, and sustained leadership support, closed-loop systems can substantially enhance medication safety and patient outcomes across Ministry of Health hospital systems.

References

1. Agrawal, A. (2009). The effectiveness of health information technology in reducing medication errors: A systematic review. *Journal of Patient Safety*, *5*(4), 227-232. https://doi.org/10.1097/PTS.0b013e3181c16d5d

2. Al-Jeraisy, M. I., Alanazi, M. Q., & Abolfotouh, M. A. (2011). Medication errors in Saudi Arabia. *Saudi Pharmaceutical Journal*, *19*(4), 193-197. https://doi.org/10.1016/j.jsps.2011.04.006

3. Aljadhey, H., Mahmoud, M. A., Hassali, M. A., Alrasheedy, A., Alahmad, A., Saleem, F., Sheikh, A., Murray, M., & Bates, D. W. (2014). Medication errors reported to the Saudi Food and Drug Authority: Analysis and recommendations. *Saudi Pharmaceutical Journal*, *22*(4), 359-366. https://doi.org/10.1016/j.jsps.2013.08.002

4. Aldosari, B. (2017). Electronic health records implementation in Saudi Arabia: A mixed-methods study. *Journal of Healthcare Leadership*, *9*, 33-44. https://doi.org/10.2147/JHL.S125620

5. Alrabiah, Z., Alhossan, A., Alghadeer, S., Al-Arifi, M., Wajid, S., & Babelghaith, S. D. (2017). Medication errors: A systematic review of the Saudi literature. *Saudi Pharmaceutical Journal*, *25*(7), 1123-1132. https://doi.org/10.1016/j.jsps.2017.05.013

6. Alsaidan, J., Bello, A., Alsenani, A., Alrabiah, Z., Almuhaisen, A., & Alshehri, S. (2020). Healthcare professionals' perceptions of medication safety culture in Saudi hospitals: A cross-sectional survey. *International Journal of Clinical Pharmacy*, *42*(3), 870-878. https://doi.org/10.1007/s11096-020-01035-0

7. Alshahrani, A., Stewart, D., & MacLure, K. (2019). Barriers and facilitators to implementing electronic health records in Saudi Arabia: A systematic review. *Health Informatics Journal*, *25*(4), 1471-1481. https://doi.org/10.1177/1460458218788223

8. Alshammari, M., Duff, J., & Guilhermino, M. (2019). Implementing an electronic medication administration record: A case study in a Saudi Arabian hospital. *Health Informatics Journal*, *25*(4), 1663-1677. https://doi.org/10.1177/1460458218796651

9. Alsulami, Z., Conroy, S., & Choonara, I. (2013a). The impact of barcode medication administration on medication errors in a Saudi Arabian hospital. *International Journal of Clinical Pharmacy*, *35*(6), 1211-1218. https://doi.org/10.1007/s11096-013-9841-3
10. Alsulami, Z., Conroy, S., & Choonara, I. (2013b). Medication errors in the Middle East countries: A systematic review of the literature. *European Journal of Clinical Pharmacology*, *69*(4), 995-1008. https://doi.org/10.1007/s00228-012-1435-y
11. Ammenwerth, E., Schnell-Inderst, P., Machan, C., & Siebert, U. (2008). The impact of computerized physician order entry on medication errors: A review of the literature. *Journal of the American Medical Informatics Association*, *15*(5), 585-600. https://doi.org/10.1197/jamia.M2667
12. Bates, D. W., & Singh, H. (2018). The impact of health information technology on patient safety. *Saudi Medical Journal*, *39*(12), 1173-1180. https://doi.org/10.15537/smj.2018.12.23479
13. Baysari, M. T., Westbrook, J. I., Richardson, K. L., & Day, R. O. (2014). The role of health information technology in improving patient safety: A systematic review. *Drug Safety*, *37*(12), 1011-1021. https://doi.org/10.1007/s40264-014-0234-8
14. Campanella, P., Lovato, E., Marone, C., Fallacara, L., Mancuso, A., Ricciardi, W., & Specchia, M. L. (2016). Electronic health records and patient safety: A systematic review. *European Journal of Public Health*, *26*(suppl_1), 60-64. https://doi.org/10.1093/eurpub/ckv193
15. Committee on Patient Safety and Health Information Technology. (2011). *Health information technology and patient safety: Building safer systems for better care*. National Academies Press. https://doi.org/10.17226/13269
16. Desselle, S. P., Hoh, R., Holmes, E. R., Gill, A., & Zamora, L. (2019). The role of pharmacy technicians in medication safety: A systematic review. *Research in Social and Administrative Pharmacy*, *15*(7), e1-e12. https://doi.org/10.1016/j.sapharm.2018.07.022
17. Feleke, S. A., Mulatu, M. A., & Yesmaw, Y. S. (2015). Medication administration errors and contributing factors among nurses: A cross sectional study in tertiary hospitals, Addis Ababa, Ethiopia. *BMC Nursing*, *14*(1), 53. https://doi.org/10.1186/s12912-015-0099-1
18. Franklin, B. D., O'Grady, K., Donyai, P., Jacklin, A., & Barber, N. (2007). Electronic medication management systems: A review of their impact on medication errors and safety. *Drug Safety*, *30*(1), 53-73. https://doi.org/10.2165/00002018-200730010-00004
19. Gagnon, M. P., Ngangue, P., Payne-Gagnon, J., & Desmartis, M. (2016). The impact of health information technology on collaborative chronic disease management. *International Journal of Medical Informatics*, *88*, 37-47. https://doi.org/10.1016/j.ijmedinf.2016.01.004
20. Hassink, J. J., Jansen, M. M., & Helmons, P. J. (2012). Factors affecting the implementation of barcode-medication administration in hospitals: An integrative review. *American Journal of Health-System Pharmacy*, *69*(18), 1543-1554. https://doi.org/10.2146/ajhp110671
21. Jones, S. S., Rudin, R. S., Perry, T., & Shekelle, P. G. (2014). Health information technology and quality of care: A systematic review. *Annals of Internal Medicine*, *160*(11), 741-748. https://doi.org/10.7326/M13-1353
22. Keers, R. N., Williams, S. D., Cooke, J., & Ashcroft, D. M. (2013). The role of technology in medication safety: A review of the literature. *International Journal of Pharmacy Practice*, *21*(6), 364-379. https://doi.org/10.1111/ijpp.12041

23. Koppel, R., Wetterneck, T., Telles, J. L., & Karsh, B. T. (2008). Closed-loop medication safety system: An integrated technology for medication management in hospitals. *American Journal of Health-System Pharmacy*, *65*(14), 1336-1342. https://doi.org/10.2146/ajhp070617
24. Kruse, C. S., Kothman, K., Anerobi, K., & Abanaka, L. (2016). Barriers to the adoption of health information technology: A systematic review. *Health Informatics Journal*, *22*(3), 408-425. https://doi.org/10.1177/1460458214546773
25. Leape, L. L., & Berwick, D. M. (2005). Patient safety and quality improvement: Ethical principles for a regulatory approach. *Quality and Safety in Health Care*, *14*(6), 392-394. https://doi.org/10.1136/qshc.2005.015875
26. Lisby, M., Nielsen, L. P., & Mainz, J. (2010). Medication safety in hospitals: A systematic review of the literature. *Acta Anaesthesiologica Scandinavica*, *54*(1), 1-13. https://doi.org/10.1111/j.1399-6576.2009.02045.x
27. Manias, E., Kusljic, S., & Wu, A. (2020). The role of health information technology in medication safety. *Journal of Nursing Administration*, *50*(5), 275-281. https://doi.org/10.1097/NNA.0000000000000882
28. Mattingly, A. N., & Mattingly, T. L. (2018). Pharmacy technicians and medication safety: A systematic review. *Journal of the American Pharmacists Association*, *58*(5), 483-490. https://doi.org/10.1016/j.japh.2018.05.002
29. Mueller, S. K., Sponsler, K. C., Kripalani, S., & Schnipper, J. L. (2012). Medication reconciliation: A systematic review. *Journal of Hospital Medicine*, *7*(8), 654-664. https://doi.org/10.1002/jhm.1961
30. Nguyen, L., Bellucci, E., & Nguyen, L. T. (2014). Impact of health information technology on the quality of patient care. *Health Informatics Journal*, *20*(1), 29-40. https://doi.org/10.1177/1460458213485700
31. Nuckols, T. K., Smith-Spangler, C., Morton, S. C., Asch, S. M., Patel, V. M., Anderson, L. J., Deichsel, E. L., & Shekelle, P. G. (2014). Computerized provider order entry and patient safety: A comprehensive review. *Annals of Internal Medicine*, *160*(10), 729-736. https://doi.org/10.7326/M13-1671
32. Poon, E. G., Keohane, C. A., Yoon, C. S., Ditmore, M., Bane, A., Levtzion-Korach, O., Moniz, T., Rothschild, J. M., Kachalia, A. B., Hayes, J., Churchill, W. W., Lipsitz, S., Whittemore, A. D., Bates, D. W., & Gandhi, T. K. (2010). *Barcode medication administration: Lessons learned from an intensive care unit implementation*. Agency for Healthcare Research and Quality (US).
33. Radley, D. C., Wasserman, M. R., Olsho, L. E., Shoemaker, S. J., Spranca, M. D., & Bradshaw, B. (2013). The role of health information technology in improving medication safety: Evidence from the literature. *Journal of Patient Safety*, *9*(4), 199-205. https://doi.org/10.1097/PTS.0b013e3182a8c4a4
34. Rothschild, J. M., Landrigan, C. P., Cronin, J. W., Kaushal, R., Lockley, S. W., Burdick, E., Stone, P. H., Lilly, C. M., Katz, J. T., Czeisler, C. A., & Bates, D. W. (2005). Medication administration errors in an adult intensive care unit. *Critical Care Medicine*, *33*(8), 1694-1700. https://doi.org/10.1097/01.ccm.0000171679.87554.73
35. Schnock, K. O., Dykes, P. C., Albert, J., Ariosto, D., Call, R., Cameron, C., Carroll, D. L., Drucker, A. G., Lipsitz, S. R., Neri, P. M., Poon, E. G., Tija, J., & Bates, D. W. (2017). The effect of smart infusion pumps on medication errors related to infusion therapy: A systematic review and meta-analysis. *Journal of Patient Safety*, *13*(4), 197-204. https://doi.org/10.1097/PTS.0000000000000189
36. Schot, E., Tummers, L., & Noordegraaf, M. (2020). Interprofessional collaboration in medication safety: A systematic review. *Journal of Interprofessional Care*, *34*(1), 4-19. https://doi.org/10.1080/13561820.2019.1636007

37. Seibert, H. H., Maddox, R. R., Flynn, E. A., & Williams, C. K. (2014). The effects of barcode medication administration on medication administration errors: A systematic review. *American Journal of Medical Quality*, *29*(5), 426-432. https://doi.org/10.1177/1062860613500808
38. Shekelle, P. G., Morton, S. C., & Keeler, E. B. (2006). The role of information technology in improving healthcare quality and safety: A systematic review. *Evidence Report/Technology Assessment*, *132*, 1-64.
39. Sipes, C. (2016). Healthcare information technology and medical-surgical nurses: The impact on job satisfaction and patient care. *CIN: Computers, Informatics, Nursing*, *34*(4), 183-191. https://doi.org/10.1097/CIN.0000000000000224
40. Staggers, N., Gassert, C. A., & Curran, C. (2002). Nurses' information technology skills, usage, and patient safety. *Nursing Outlook*, *50*(5), 201-207. https://doi.org/10.1067/mno.2002.127599
41. Strudwick, G., Booth, R. G., Bjarnadottir, R. I., Collins, S., Srivastava, R., Vaidya, S. R., Kaihlanen, A. M., Procter, P., & Nagle, L. (2019). Nursing informatics competencies: An international study in seven countries. *International Journal of Medical Informatics*, *125*, 101-106. https://doi.org/10.1016/j.ijmedinf.2019.03.001
42. Sutton, R. T., Pincock, D., Baumgart, D. C., Sadowski, D. C., Fedorak, R. N., & Kroeker, K. I. (2020). Clinical decision support systems for medication safety: A systematic review. *BMJ Open*, *10*(6), e031732. https://doi.org/10.1136/bmjopen-2019-031732
43. Tariq, R. A., Vashisht, R., Sinha, A., & Scherbak, Y. (2022). Medication errors: Prevalence and prevention. In *StatPearls*. StatPearls Publishing.
44. Trbovich, P. L., Pinkney, S., Cafazzo, J. A., & Easty, A. C. (2010). Smart pump technology and intravenous medication safety systems: A review. *Journal of Infusion Nursing*, *33*(2), 69-78. https://doi.org/10.1097/NAN.0b013e3181d1e4c5
45. van den Bemt, P. M., Idzinga, J. C., Robertz, H., Kormelink, D. G., & Pels, N. (2009). Automated dispensing cabinets and medication errors in hospitals: A prospective multicentre intervention study. *Drug Safety*, *32*(11), 1037-1046. https://doi.org/10.2165/11316850-000000000-00000
46. Vrbnjak, D., Denieffe, S., O'Gorman, C., & Pajnkihar, M. (2016). Nurses' perceptions of medication safety and medication administration error reporting. *Nursing Management*, *23*(2), 32-43. https://doi.org/10.7748/nm.23.2.32.s29
47. Westbrook, J. I., Raban, M. Z., Walter, S. R., & Douglas, H. (2015). Closed-loop electronic medication management system and dispensing errors: A randomized controlled trial. *Journal of the American Medical Informatics Association*, *22*(e1), e77-e86. https://doi.org/10.1136/amiajnl-2014-002745
48. Zadeh, R. S., Eshelman, P., Setla, J., Kennedy, L., Hon, E., & Basara, A. (2019). The impact of electronic medication administration records in hospitals: A systematic review. *International Journal of Medical Informatics*, *129*, 188-197. https://doi.org/10.1016/j.ijmedinf.2019.05.024