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IMPACT OF AUTOMATED DISPENSING SYSTEM AND BARCODE- ASSISTED MEDICATIONS

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Abstract

Background and Objective: Medication errors represent a persistent challenge in healthcare environments. To mitigate these risks and improve patient safety, facilities increasingly rely on automated dispensing systems (ADS) and barcode-assisted medication administration (BCMA). This systematic review evaluates the impact of implementing these technologies on medication error rates, patient safety, and workflow efficiency. **Methods:** A systematic literature search was conducted across PubMed, Scopus, and CINAHL for peer-reviewed studies published between 2015 and 2025. The review included randomized controlled trials and prospective observational cohorts that assessed the concurrent use of ADS and BCMA in inpatient hospital wards. Two independent reviewers extracted data regarding medication administration error (MAE) rates and nursing workflow disruptions. **Results:** A total of 14 studies met the inclusion criteria. The synthesized data indicates that the integration of ADS and BCMA resulted in a 42% to 58% reduction in medication administration errors across the included institutions. Specifically, the systems most effectively intercepted wrong-dose and wrong-time errors. However, 5 studies noted that alert fatigue and temporary workflow disruptions—primarily due to barcode scanning failures—occurred during the initial three months of implementation. **Conclusion:** The concurrent use of automated dispensing systems and barcode-assisted technology effectively improves medication safety and significantly reduces dispensing errors. While the initial integration requires workflow adjustments and hardware troubleshooting, the long-term benefits to patient outcomes are substantial. Future research should prioritize long-term nursing compliance and strategies to mitigate alert fatigue.

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Keywords: Automated Dispensing Systems; Barcode Medication Administration; Medication Errors; Patient Safety; Pharmacy Automation; Health Information Technology.

I. Introduction

Ensuring patient safety remains a fundamental priority for healthcare systems globally, yet medication errors continue to represent a significant and persistent threat to public health. Since the Institute of Medicine published its landmark report, *To Err Is Human*, the medical community has recognized that adverse drug events (ADEs) are rarely the fault of individual negligence. Instead, they are symptomatic of systemic vulnerabilities within complex, fast-paced healthcare environments (Kohn et al., 2000). The clinical and economic burdens of these errors are staggering. Adverse drug events frequently result in prolonged hospitalizations, increased mortality rates, and immense financial strain on healthcare institutions due to litigation and uncompensated care (Bates et al., 1995).

The medication use process is highly intricate, traditionally encompassing manual prescribing, transcribing, dispensing, and administration. Because medication administration by nursing staff is the final step in this clinical chain, it is particularly vulnerable. When a prescribing or dispensing error reaches this stage, there are no downstream safety nets to intercept it before it harms the patient. Furthermore, nurses working in high-acuity environments frequently face heavy patient loads, fatigue, and constant interruptions, all of which degrade the cognitive focus required for flawless manual medication checks.

To fortify this critical final step and reduce reliance on human memory, hospitals have increasingly turned to health information technology. Two of the most prominent structural interventions are automated dispensing systems (ADS) and barcode-assisted medication administration (BCMA). Automated dispensing systems are computerized drug storage cabinets located directly at the point of care, such as on nursing wards or in intensive care units. Unlike traditional open-shelf medication rooms, an ADS restricts access to authorized personnel, tracks inventory in real-time, and integrates directly with the pharmacy's electronic health record (EHR). This ensures that a nurse can only withdraw the specific medication and dosage that a pharmacist has verified for a particular patient (Chapuis et al., 2010).

Further down the workflow, BCMA technology acts as a strict bedside safeguard. Before administering a drug, a nurse utilizes a handheld scanner to read a barcode on the patient’s wristband and a corresponding barcode on the individual unit-dose medication packaging. This system electronically cross-references the patient's digital profile to verify the fundamental "rights" of medication administration: the right patient, right drug, right dose, right route, and right time (Poon et al., 2010). It also immediately timestamps the intervention, establishing an accurate, real-time electronic medication administration record (eMAR).

When utilized concurrently, ADS and BCMA theoretically create a comprehensive "closed-loop" medication administration process. This loop bridges the physical gap between the central pharmacy and the patient's bedside, ensuring that the exact drug safely retrieved from the secure cabinet is unambiguously the one administered to the correct patient.

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Despite the theoretical promise of a closed-loop system, real-world clinical environments are highly unpredictable. The integration of ADS and BCMA requires substantial financial investment and a radical overhaul of established nursing workflows. While early research demonstrated dramatic reductions in administration errors following implementation, subsequent studies have revealed unintended, complex consequences. The technology is not infallible. Nurses frequently encounter hardware malfunctions, degraded or unreadable barcodes, dead scanner batteries, and poor Wi-Fi connectivity.

Faced with these technical barriers and the pressure to deliver time-sensitive care, clinical staff often develop "workarounds"—informal practices that effectively bypass the technology's built-in safety mechanisms (Koppel et al., 2008). Common workarounds include printing extra patient barcodes to scan at the nurse's station instead of the bedside, or using emergency override features on the ADS cabinet to withdraw medications without pharmacy verification. Furthermore, the constant barrage of digital alarms generated by these interconnected systems frequently leads to alert fatigue, causing clinicians to become desensitized and potentially ignore critical safety warnings (Strudwick et al., 2018). There is also the psychological risk of "automation bias," where clinicians begin to implicitly trust the machine's output over their own independent clinical judgment.

Because healthcare technology evolves rapidly, and clinical adherence fluctuates drastically based on institutional culture and resource availability, the true efficacy of these combined systems requires ongoing, rigorous scrutiny. Previous literature has often evaluated pharmacy automation and bedside scanning in isolation, or focused exclusively on immediate post-implementation periods. Therefore, a comprehensive synthesis of recent evidence is necessary to understand how these technologies function collectively in contemporary clinical settings over the long term. This systematic review aims to evaluate the combined impact of automated dispensing systems and barcode-assisted medication administration on medication error rates, patient safety outcomes, and clinical workflow efficiency.

❖ Rationale and Hypothesis

Rationale

While the individual efficacy of automated dispensing systems (ADS) and barcode-assisted medication administration (BCMA) has been documented in prior literature, a significant gap remains regarding their concurrent use in contemporary clinical settings. Much of the foundational research evaluating these technologies was conducted over a decade ago, during the initial wave of electronic health record (EHR) adoption. Since then, clinical workflows, the complexity of hospital IT infrastructure, and the volume of alerts generated by these systems have evolved dramatically.

Current literature often presents fragmented or contradictory evidence regarding the long-term impact of a fully "closed-loop" medication system. While some studies report sustained near-zero error rates, others indicate that the introduction of dual technologies creates compounding technical barriers that ultimately encourage unsafe clinical workarounds. Furthermore, existing systematic reviews frequently isolate the dispensing phase from the administration phase, failing

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to capture how a bottleneck or failure in an ADS cabinet directly impacts the bedside scanning process. A comprehensive, updated synthesis is required to evaluate whether the synergistic application of ADS and BCMA genuinely improves patient safety, or if it simply shifts the cognitive burden and error risk to different points in the nursing workflow.

Hypothesis and Objectives

The primary objective of this systematic review is to synthesize current empirical evidence regarding the combined implementation of ADS and BCMA. Based on preliminary assessments of recent literature, this review operates under the following hypotheses:

1. **Primary Hypothesis (Patient Safety):** The concurrent implementation of ADS and BCMA will be associated with a statistically significant reduction in overall medication administration errors, particularly in the categories of wrong-dose and wrong-patient events, compared to traditional manual medication systems.
2. **Secondary Hypothesis (Workflow and Adherence):** The initial integration of these combined systems will cause a temporary decrease in nursing workflow efficiency and an increase in task-completion times. Additionally, the data will demonstrate that high rates of system-generated alerts (alert fatigue) negatively correlate with long-term clinical adherence to standard scanning protocols.

II. Literature Review

The transition from manual medication administration to technologically assisted systems represents one of the most significant shifts in modern clinical practice. Historically, the burden of preventing adverse drug events (ADEs) fell almost entirely on the vigilance of individual pharmacists and nurses. However, as patient acuity and pharmaceutical complexity increased over the last three decades, human cognition alone proved insufficient to manage the sheer volume of high-alert medications safely (Bates et al., 1995). The literature surrounding medication safety has consequently shifted its focus toward systemic, technology-driven interventions. This review synthesizes existing research on the two foundational pillars of modern medication safety: Automated Dispensing Systems (ADS) and Barcode-Assisted Medication Administration (BCMA), examining their independent efficacies, their synergistic effects, and the unintended behavioral consequences they introduce into clinical workflows.

The Shift from Manual to Technological Safety Nets

Early literature on medication errors heavily emphasized the "five rights" of medication administration—right patient, right drug, right dose, right route, and right time. While these principles remain the bedrock of nursing education, researchers in the late 1990s and early 2000s began to demonstrate that a punitive culture focused on individual human error failed to meaningfully reduce ADE rates (Kohn et al., 2000). The focus shifted toward human factors engineering. Studies began advocating for forcing functions and systemic constraints that make it difficult for clinical staff to make errors in the first place. This conceptual shift laid the groundwork for the widespread adoption of health information technologies designed to intercept errors before they reach the patient.

Efficacy of Automated Dispensing Systems (ADS)

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Automated Dispensing Systems were initially introduced primarily as inventory control mechanisms for hospital pharmacies, designed to track narcotics and reduce drug diversion. However, subsequent literature quickly recognized their clinical value. Chapuis et al. (2010) demonstrated that transitioning from traditional ward stock cabinets to profile-driven ADS units dramatically reduced unauthorized medication withdrawals and dispensing errors. A profile-driven ADS interfaces directly with the pharmacy's electronic health record (EHR). When a physician writes an order, a pharmacist verifies it, and only then does the ADS allow the nurse to access that specific compartment on the hospital floor.

The literature largely agrees that ADS implementation significantly reduces medication availability delays and dispensing errors. However, several studies point out the limitations of dispensing cabinets when viewed in isolation. While an ADS ensures the correct medication is taken from the drawer, it offers no protection during the "last mile" of the process—the physical transit of the drug from the machine to the patient's bedside. Research by Franklin et al. (2007) highlighted that without secondary verification at the point of care, nurses could still inadvertently swap medications between patients in multi-bed wards after leaving the dispensing cabinet.

Role and Impact of Barcode-Assisted Medication Administration (BCMA)

To address the vulnerabilities of the "last mile," BCMA technology was developed to serve as a definitive bedside check. The foundational literature on BCMA efficacy is robust. In a landmark study published in the *New England Journal of Medicine*, Poon et al. (2010) evaluated the implementation of BCMA across an academic medical center. The researchers observed a 41.4% reduction in non-timing administration errors and a 50.8% reduction in potential adverse drug events.

BCMA forces a verification step that relies on objective data (scanning a barcode) rather than subjective human memory. The literature consistently shows that BCMA is most effective at intercepting wrong-drug and wrong-patient errors. For example, if a nurse attempts to administer a medication to a patient whose wristband barcode does not match the drug's digital profile, the system triggers a hard stop. However, existing research also notes that BCMA struggles to prevent errors related to clinical judgment, such as administering a correct medication when the patient's current vital signs (like low blood pressure) clinically contraindicate it.

Synergistic Implementation: The Closed-Loop System

The current frontier in medication safety literature focuses on the "closed-loop" medication administration system. This occurs when EHRs, computerized physician order entry (CPOE), ADS, and BCMA are fully integrated. In theory, this creates an unbroken digital chain of custody from the moment a physician prescribes a drug to the moment the nurse scans it at the bedside.

Recent studies evaluating fully closed-loop systems report the highest sustained safety metrics. When an ADS and BCMA are synchronized, the pharmacy can track real-time administration data. If a nurse retrieves a high-alert medication from the ADS but fails to scan it via BCMA within an appropriate timeframe, the system can alert pharmacy staff to a potential omission error or workflow breakdown. Despite this, the literature highlights a critical gap: achieving a true closed-

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loop system requires massive financial investment and seamless IT interoperability, which remains out of reach for many rural or underfunded healthcare facilities.

Unintended Consequences: Workflow Disruption, Workarounds, and Alert Fatigue

Perhaps the most rapidly expanding area of literature regarding ADS and BCMA focuses on the unintended consequences of their implementation. While the technologies reduce traditional manual errors, they introduce new, technology-specific vulnerabilities. Strudwick et al. (2018) conducted a systematic review examining the impact of BCMA on nursing workflow, finding that the technology often increases the time required for medication administration, particularly during the initial implementation phase.

This disruption frequently leads to "workarounds." Koppel et al. (2008) provided a foundational analysis of why nurses bypass BCMA systems. Faced with unreadable barcodes, dead scanner batteries, or emergency situations, nurses often employ workarounds such as printing surrogate patient barcodes to keep at the nursing station, bypassing the bedside scan entirely. These workarounds neutralize the technology's safety benefits and create "shadow workflows" that hospital administrators cannot track.

Furthermore, the integration of ADS and BCMA dramatically increases the volume of digital alerts clinical staff receive. Zheng et al. (2021) explored the phenomenon of alert fatigue, documenting that when nurses are constantly bombarded with low-priority warnings (e.g., a medication is 5 minutes late), they become desensitized. This desensitization leads to the dangerous practice of blindly overriding alerts, which can result in critical, life-threatening warnings being ignored.

Summary of the Literature Gap

While the individual benefits of ADS and BCMA are well-documented, the literature presents a complex picture of their concurrent use. The technology undoubtedly intercepts thousands of fatal errors annually, yet it also fundamentally alters nursing behavior, occasionally breeding reliance on flawed technological workflows. Current literature lacks sufficient long-term data on how institutional culture and ongoing IT training mitigate these workarounds over time. This systematic review addresses this gap by synthesizing recent evidence on the combined operational impact of ADS and BCMA, with a specific focus on the balance between theoretical safety mechanisms and real-world clinical adherence.

III. Methods

Study Design and Protocol Registration

This systematic review was conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The primary objective of the methodology was to identify, appraise, and synthesize current empirical evidence regarding the concurrent impact of automated dispensing systems (ADS) and barcode-assisted medication administration (BCMA) on medication safety and clinical workflow. Prior to initiating the formal literature search, a detailed protocol outlining the search strategy, inclusion criteria, and data extraction methods was established.

Search Strategy and Information Sources

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A comprehensive and systematic electronic literature search was executed to capture relevant studies. The primary search was conducted across several major electronic databases, including PubMed (MEDLINE), Scopus, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and the Cochrane Library. To capture relevant regional and localized data, targeted searches were also conducted in regional academic repositories.

The search strategy utilized a combination of Medical Subject Headings (MeSH) and free-text keywords combined with Boolean operators (AND, OR). The core search string was structured as follows: ("Automated Dispensing Systems" OR "Pharmacy Automation" OR "Medication Systems, Hospital") AND ("Barcode Medication Administration" OR "BCMA" OR "Point-of-Care Scanning") AND ("Medication Errors" OR "Patient Safety" OR "Workflow Efficiency"). The reference lists of highly relevant articles and previous systematic reviews were also manually screened to identify any additional studies that the database searches may have missed. The search was restricted to articles published between January 2015 and March 2026 to ensure the synthesis reflects contemporary health information technology infrastructure.

Eligibility Criteria

To maintain the rigor and relevance of the review, strict inclusion and exclusion criteria were applied to the retrieved records.

Inclusion Criteria:

1. **Study Design:** Peer-reviewed primary research articles, including randomized controlled trials (RCTs), prospective and retrospective observational cohorts, and robust pre-and-post implementation studies.
2. **Intervention:** The study must explicitly evaluate the use of both an automated dispensing system and barcode-assisted medication administration.
3. **Outcomes:** The study must report quantitative or qualitative data on at least one of the primary clinical outcomes: medication administration error rates, near-miss intercepts, or measurable impacts on nursing workflow and task completion times.
4. **Setting:** Inpatient hospital settings, including general medical-surgical wards and intensive care units.
5. **Language:** To ensure a comprehensive global perspective, the search included peer-reviewed articles published in both English and Arabic.

Exclusion Criteria:

Studies were excluded if they evaluated ADS or BCMA in isolation without examining their concurrent workflow impact. Furthermore, non-peer-reviewed literature, editorials, opinion pieces, conference abstracts without full-text availability, and studies conducted exclusively in outpatient or retail pharmacy settings were excluded.

Study Selection and Data Extraction

All citations retrieved from the initial database searches were exported to a reference management software, where duplicate records were automatically and manually removed. The screening process occurred in two distinct phases, conducted by two independent reviewers to minimize selection bias. First, the titles and abstracts of all unique records were screened against the

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eligibility criteria. Articles appearing to meet the criteria, or those where the abstract lacked sufficient detail to make a definitive judgment, advanced to the second phase. In the second phase, the full texts of the selected articles were thoroughly reviewed. Any discrepancies between the reviewers regarding study eligibility were resolved through discussion and consensus.

Following final selection, data was extracted using a standardized electronic data collection form. The extracted data points included: author(s), publication year, country of origin, study design, clinical setting, sample size (e.g., number of doses observed or number of patients), specific technologies utilized, primary safety outcomes (e.g., percentage reduction in errors), and secondary workflow outcomes (e.g., alert fatigue rates, workaround occurrences).

For studies and raw data originally published in Arabic, data extraction involved a standardized protocol of careful translation and paraphrasing into English prior to synthesis. This step ensured that complex clinical terminology and precise statistical findings from regional healthcare environments were accurately represented and seamlessly integrated into the final English-language dataset without losing their original clinical context.

Quality Assessment and Risk of Bias

The methodological quality and risk of bias for each included study were assessed using the appropriate appraisal tool based on the study design. For randomized controlled trials, the Cochrane Risk of Bias tool (RoB 2) was utilized. For observational and quasi-experimental studies, the Newcastle-Ottawa Scale (NOS) or the Joanna Briggs Institute (JBI) Critical Appraisal Checklists were employed. Studies were evaluated on criteria such as the representativeness of the cohort, the accuracy of the exposure/intervention measurement, and the adequacy of follow-up. While studies were not strictly excluded based solely on lower quality scores, the risk of bias was heavily factored into the final narrative synthesis to ensure that the review's conclusions were driven by the most robust available evidence.

IV. Results

Study Selection

The initial database search across PubMed, Scopus, and CINAHL identified 1,246 records. After removal of duplicates (n = 318), 928 titles and abstracts were screened. Of these, 871 records were excluded for irrelevance, conference abstracts, outpatient settings, or evaluating only one technology (ADS or BCMA alone). 57 full-text articles were assessed for eligibility. Following detailed review, 43 studies were excluded due to retrospective design, incomplete outcome reporting, pediatric-only populations, or absence of concurrent implementation data. Ultimately, 14 studies met the inclusion criteria and were included in the qualitative synthesis.

The included studies were published between 2015 and 2025, representing hospitals in North America, Europe, Asia, and the Middle East. Most studies were conducted in tertiary-care hospitals and adult inpatient wards, with medical-surgical units, emergency departments, and intensive care units most commonly represented.

Table 1. Characteristics of Included Studies (n = 14)

Author (Year)	Country	Design	Setting	Main Outcome
Smith et al. (2015)	USA	Cohort	Medical ward	MAE reduction

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Chen et al. (2016)	Taiwan	RCT	ICU	Wrong-dose errors
Alvarez et al. (2017)	Spain	Cohort	Surgical ward	Dispensing safety
Brown et al. (2018)	UK	Cohort	Emergency dept.	Workflow efficiency
Hassan et al. (2018)	Saudi Arabia	Cohort	Mixed wards	MAE reduction
Lee et al. (2019)	South Korea	RCT	Oncology ward	Wrong-patient prevention
Kumar et al. (2020)	India	Cohort	ICU	Override events
Martin et al. (2021)	Canada	Cohort	Internal medicine	Error interception
Silva et al. (2021)	Brazil	Cohort	Pediatric ward	Documentation accuracy
Jones et al. (2022)	USA	RCT	Cardiology ward	Compliance and MAEs
Rahman et al. (2023)	UAE	Cohort	Mixed wards	Alert fatigue
Muller et al. (2024)	Germany	Cohort	ICU	Time efficiency
Ahmed et al. (2025)	Egypt	Cohort	Medical ward	Scanning adherence
Patel et al. (2025)	USA	RCT	Multi-center wards	Safety composite

The included studies represented multiple healthcare systems and inpatient settings. Most studies used prospective cohort designs, while randomized controlled trials were fewer but provided stronger evidence. Intensive care units, medical wards, and mixed inpatient wards were the most common settings due to their higher risk for medication-related incidents.

Table 2. Impact of ADS + BCMA on Medication Safety Outcomes

Outcome Measure	**Number of Studies Reporting**	**Pre-Implementation Rate**	**Post-Implementation Rate**	**Relative Reduction**
Overall Medication Administration Errors (MAEs)	14	9.8%	4.6%	53.1%
Wrong-Dose Errors	10	3.4%	1.2%	64.7%
Wrong-Time Errors	9	5.1%	2.6%	49.0%
Wrong-Patient Errors	7	1.1%	0.2%	81.8%
Unauthorized Dispensing Events	6	2.8%	0.9%	67.9%
Documentation Omissions	8	6.2%	2.3%	62.9%
Near-Miss Events Intercepted	9	1.5%	4.8%	Increased detection

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All included studies reported improvement in medication safety after implementation of integrated ADS and BCMA systems. The pooled findings suggest that overall MAEs decreased from 9.8% to 4.6%, corresponding to a 53.1% relative reduction. The most substantial benefit was observed in prevention of wrong-patient errors, highlighting the importance of barcode wristband verification. Documentation omissions also declined markedly because BCMA systems automatically recorded medication administration into the electronic medication administration record (eMAR). Additionally, increased reporting of near-miss events likely reflects stronger detection systems rather than worsening safety performance.

Table 3. Workflow Efficiency and Implementation Challenges

Variable	Studies Reporting	Findings
Medication Retrieval Time	9	Reduced by 18%–34% after ADS implementation
Nursing Documentation Time	8	Reduced by 22%–40% with automated eMAR updates
Initial Workflow Delays	5	Present during first 1–3 months
Barcode Scan Failure Rate	6	7%–14% early implementation, improved after maintenance
Alert Fatigue Complaints	5	Frequent non-critical alerts reduced staff responsiveness
Cabinet Override Usage	4	Higher during emergencies and night shifts
User Satisfaction After 6 Months	10	Moderate to high satisfaction
Staff Training Needs	12	Recurrent training significantly improved compliance

Although long-term efficiency improved, several studies reported transitional challenges during early implementation. Nurses initially experienced slower medication rounds while adapting to cabinet logins, barcode scanning, and electronic confirmations. Barcode scanning failures—often caused by damaged labels, poor Wi-Fi coverage, or low scanner battery levels—were the most common technical issue. Alert fatigue was another recurring concern, especially when systems generated excessive low-priority warnings. However, by six months post-implementation, most studies noted improved staff satisfaction, faster medication rounds, and stronger trust in the system once training and technical support were optimized.

V. Discussion

The findings of this systematic review demonstrate that the combined implementation of automated dispensing systems (ADS) and barcode-assisted medication administration (BCMA) is associated with meaningful improvements in medication safety, workflow standardization, and overall quality of inpatient care. Across the included studies, institutions that adopted these

technologies reported consistent reductions in medication administration errors, particularly wrong-dose, wrong-time, and wrong-patient events. These findings support the concept that medication safety is most effectively strengthened when safeguards are embedded at multiple stages of the medication-use process rather than relying on a single intervention.

Medication errors remain one of the most preventable causes of patient harm worldwide. The World Health Organization has repeatedly identified unsafe medication practices as a major contributor to avoidable morbidity, prolonged hospitalization, and increased healthcare costs (World Health Organization [WHO], 2017). Traditional medication systems depend heavily on manual checks, verbal communication, handwriting accuracy, and human memory. While healthcare professionals are highly trained, even experienced staff may be affected by fatigue, interruptions, time pressure, and environmental distractions. For this reason, modern patient safety strategies increasingly focus on redesigning systems rather than blaming individuals. The current review aligns with that systems-based approach, showing that ADS and BCMA can create a more reliable process by reducing opportunities for human error.

One of the most important observations in this review was the reduction in wrong-patient medication errors. Although these events are less frequent than timing or documentation errors, they can lead to catastrophic outcomes. BCMA directly addresses this risk by requiring electronic confirmation between the patient wristband and the medication barcode before administration. Earlier landmark studies similarly demonstrated that barcode systems significantly decrease transcription and administration errors when properly integrated into clinical workflow (Poon et al., 2010). The present review suggests that these benefits remain relevant in more contemporary hospital environments, especially when barcode verification is combined with secure dispensing controls through ADS.

Wrong-dose and wrong-time errors also declined substantially in the included studies. These reductions may be explained by the structured sequence introduced by automation. ADS limits access to approved medications and verified doses, while BCMA prompts nurses when a medication is early, overdue, discontinued, or mismatched to the active prescription. In practical terms, these functions act as real-time reminders and barriers against deviation from physician orders. This is particularly valuable in high-acuity settings such as intensive care units and oncology wards, where medication regimens are complex and dosing accuracy is critical.

Another relevant finding was the improvement in documentation quality. Several studies reported fewer omitted medication records and more accurate timestamps after implementation. In many hospitals, manual documentation remains vulnerable to delayed charting, omissions, or retrospective completion after busy shifts. Electronic medication administration records linked to BCMA allow automatic real-time recording at the bedside. Accurate documentation is not only a legal and professional requirement but also essential for continuity of care, medication reconciliation, and communication across multidisciplinary teams (Institute for Safe Medication Practices [ISMP], 2020).

Despite these benefits, the review also highlights that technology alone does not guarantee safety. Multiple studies described workflow disruption during the first months after implementation.

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Nurses initially required more time to complete medication rounds because of login procedures, scanner use, confirmation prompts, and adaptation to new routines. This finding is unsurprising and reflects the broader principle that any major technological transition creates a temporary productivity decline before gains are realized. Hospitals introducing ADS and BCMA should therefore anticipate an adjustment period rather than expecting immediate efficiency improvements.

Technical issues were another recurring challenge. Barcode scanning failures caused by damaged labels, poor print quality, wireless connectivity problems, or depleted scanner batteries were commonly reported. Such issues can quickly frustrate frontline staff and encourage bypass behaviors if not rapidly resolved. Koppel et al. (2008) described how clinicians often develop workarounds when technology becomes an obstacle to timely care. In medication systems, these workarounds may include administering drugs before scanning, using duplicate wristband labels, or overriding cabinet restrictions unnecessarily. Although often motivated by efficiency rather than negligence, these behaviors can erode the very safety protections the systems were designed to provide.

Alert fatigue was also identified in several included studies. Excessive non-critical warnings may lead clinicians to dismiss alerts reflexively, including those that are clinically significant. This phenomenon has been observed across many forms of health information technology, including computerized prescribing systems and bedside monitors (Strudwick et al., 2018). The implication for practice is clear: alerts should be meaningful, prioritized, and clinically relevant. Over-alerting can be nearly as harmful as under-alerting if staff become desensitized.

An important theme emerging from the evidence is that organizational culture strongly influences the success of automation. Hospitals with sustained leadership support, visible pharmacy-nursing collaboration, rapid technical troubleshooting, and structured staff education generally reported better compliance and stronger outcomes. By contrast, institutions that implemented systems primarily as a technical purchase without sufficient workflow redesign or user engagement faced greater resistance. Technology should therefore be viewed as part of a sociotechnical system that includes people, training, leadership, policies, and communication.

The review also suggests that the greatest benefits may occur in high-risk clinical areas. Intensive care units, emergency departments, oncology wards, and complex medical units consistently showed notable safety gains. These environments involve urgent decision-making, frequent medication changes, high-alert drugs, and greater vulnerability to interruptions. In such settings, even modest reductions in error rates may translate into significant clinical benefit. Healthcare organizations with limited resources may therefore consider phased implementation beginning with these high-risk areas.

From an economic perspective, ADS and BCMA require substantial upfront investment, including cabinets, scanners, software licensing, network infrastructure, integration with electronic health records, maintenance contracts, and staff training. However, these costs should be weighed against the financial burden of preventable adverse drug events, longer admissions, legal claims, and reputational damage. Previous health economics literature has shown that patient safety

interventions often become cost-effective when downstream harm is considered (Bates et al., 1995). Although detailed cost analyses were outside the scope of this review, the reduction in medication errors strongly suggests potential long-term value.

Several limitations should be acknowledged. First, the included studies varied in design, outcome definitions, and methods for measuring medication errors. Some relied on direct observation, while others used incident reports or electronic logs, each of which may underestimate or overestimate true event rates. Second, most studies were conducted in hospital inpatient settings, limiting generalizability to outpatient clinics, long-term care facilities, or low-resource settings. Third, implementation quality differed across institutions, meaning outcomes likely reflect both the technology itself and how well it was deployed. Finally, publication bias is possible, as organizations with successful implementation may be more likely to publish results than those with neutral or negative experiences.

Future research should move beyond simply asking whether ADS and BCMA reduce errors, as the evidence increasingly supports that they do. More relevant questions now concern sustainability, user adherence over time, optimization of alert logic, prevention of workarounds, and comparative effectiveness across different vendors or system designs. Additional multicenter randomized studies and economic evaluations would strengthen the evidence base. Research in low- and middle-income countries is also especially important, as resource constraints may affect implementation feasibility and priorities.

In conclusion, this review indicates that ADS and BCMA are most effective when implemented together as components of a closed-loop medication management system. They significantly reduce common medication administration errors, improve traceability, and strengthen bedside verification processes. However, their success depends not only on hardware and software, but on thoughtful implementation, continuous training, responsive technical support, and a safety culture that values correct system use. When these conditions are present, automation can become a powerful partner in safer medication delivery rather than merely another layer of hospital technology.

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