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Adoption and Effectiveness of Automated Dispensing Cabinets in Reducing Medication Errors in Saudi Tertiary Care Centers

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Abstract

Objective: This study aimed to evaluate the adoption, utilization, and perceived effectiveness of automated dispensing cabinets (ADCs) in tertiary care hospitals in Saudi Arabia and to assess their impact on medication safety and workflow efficiency.
Methods: A cross-sectional, mixed-methods design was employed, including 400 healthcare professionals (nurses, pharmacists, and pharmacy technicians) across medical, surgical, and critical care units. Quantitative data included ADC utilization metrics and retrospective analysis of medication error reports before and after ADC implementation. Qualitative data were collected through open-ended survey items to identify facilitators and challenges associated with ADC use. Descriptive and inferential statistics were applied, and thematic analysis was conducted for qualitative responses.
Results: ADCs were widely adopted and frequently utilized, with users accessing systems an average of 18 times per shift. Healthcare professionals reported overwhelmingly positive perceptions regarding ADC effectiveness, usability, and workflow integration. Implementation of ADCs was associated with a substantial reduction in overall medication errors (–25.3%), particularly in dispensing and preparation stages. Qualitative findings highlighted that structured training, organizational support, and integration with electronic systems were key facilitators, while minor workflow adjustments and technical challenges were manageable.
Conclusion: ADCs are effective, well-accepted, and integral to improving medication safety and workflow efficiency in tertiary care settings. Their success depends on comprehensive training, strong institutional support, and integration with electronic medication management systems. Complementary interventions are recommended to address administration-stage errors, and future research should explore long-term sustainability and integration with emerging technologies.

Keywords: Automated dispensing cabinets, medication safety, workflow efficiency, healthcare technology, tertiary care hospitals, Saudi Arabia.

INTRODUCTION

Medication errors constitute a persistent and critical challenge to patient safety within contemporary healthcare systems, particularly in tertiary care centers characterized by high patient acuity, complex

therapeutic regimens, and intensive multidisciplinary workflows. Errors occurring across the medication-use continuum—encompassing prescribing, dispensing, preparation, and administration—have been consistently associated with preventable adverse drug events, increased morbidity and mortality, prolonged hospitalization, and substantial economic burden. Consequently, enhancing the safety and reliability of medication management processes has emerged as a central priority for healthcare organizations and policymakers worldwide.

In this context, the integration of health information technologies and automation has been widely promoted as a strategic approach to mitigating human error and strengthening system-level safeguards. Automated dispensing cabinets (ADCs) have become a prominent component of hospital medication management infrastructure, particularly within high-acuity clinical environments. These decentralized, computerized drug storage and dispensing systems are designed to provide secure, controlled access to medications at the point of care, while incorporating functionalities such as user authentication, real-time inventory tracking, transaction auditing, and electronic documentation. When effectively integrated with complementary systems such as computerized physician order entry and electronic medication administration records, ADCs are intended to enhance accountability, reduce dispensing discrepancies, and improve the efficiency of nursing and pharmacy workflows.

Notwithstanding their widespread adoption, the evidence base regarding the effectiveness of ADCs in reducing medication errors remains heterogeneous. While numerous studies have demonstrated reductions in dispensing- and administration-related errors following ADC implementation, others have reported the emergence of technology-induced errors linked to system configuration, override practices, workflow disruptions, and insufficient user training. These divergent findings suggest that the safety impact of ADCs is highly context-dependent and mediated by organizational factors, including implementation strategies, governance structures, staff competencies, and safety culture. As such, rigorous, setting-specific evaluations are essential to elucidate the conditions under which ADCs can meaningfully contribute to medication safety.Within Saudi Arabia, ongoing healthcare transformation initiatives under Vision 2030 have placed strong emphasis on patient safety, quality of care, and digital health innovation. Tertiary care centers across the Kingdom have increasingly invested in advanced medication-use technologies, including ADCs, as part of broader efforts to modernize hospital operations and align with international accreditation standards. However, despite this rapid technological uptake, empirical research examining the adoption, utilization, and effectiveness of ADCs in the Saudi tertiary care context remains scarce. Differences in healthcare system organization, workforce composition, clinical practice patterns, and regulatory oversight underscore the need for locally generated evidence rather than reliance on findings from other healthcare settings.

Accordingly, the present study seeks to critically examine the adoption and effectiveness of automated dispensing cabinets in reducing medication errors within Saudi tertiary care centers. By assessing both the extent of ADC implementation and their impact on medication safety outcomes, this research aims to contribute robust, contextually relevant evidence to inform institutional policy, guide implementation and optimization strategies, and support national patient safety objectives. Ultimately, a nuanced understanding of the role of ADCs in Saudi tertiary hospitals is essential to maximizing the return on health technology investments and advancing safer, more resilient medication-use systems.

Research Objectives

General Objective

To evaluate the adoption and effectiveness of automated dispensing cabinets in reducing medication errors in Saudi tertiary care centers.

Specific Objectives

1. To assess the level of automated dispensing cabinet adoption and patterns of use in Saudi tertiary care hospitals.
2. To examine the impact of automated dispensing cabinets on medication error rates and types.
3. To explore healthcare professionals' perceptions of the effectiveness of automated dispensing cabinets in enhancing medication safety.

4. To identify key factors influencing the effective implementation and use of automated dispensing cabinets.

Research Questions

1. What is the extent of automated dispensing cabinet adoption in Saudi tertiary care centers?
2. How does the use of automated dispensing cabinets affect medication error rates and types?
3. How do healthcare professionals perceive the role of automated dispensing cabinets in reducing medication errors?
4. What factors facilitate or hinder the effective use of automated dispensing cabinets in Saudi tertiary care hospitals?

LITERATURE REVIEW

Medication errors continue to represent a major threat to patient safety globally, with implications for morbidity, mortality, and healthcare costs (Saudi Patient Safety Centre, 2025). Errors may occur at multiple points in the medication-use cycle, including prescribing, dispensing, and administration, and are frequently cited as among the most common preventable adverse events in hospital settings (Saudi Patient Safety Centre, 2025). In response, health systems increasingly adopt technologies intended to interlace safety mechanisms with clinical workflow processes. Among these, automated dispensing cabinets (ADCs) have been widely implemented to improve medication storage and distribution processes at the point of care.

ADCs are computerized, decentralized drug storage and dispensing systems that aim to streamline medication distribution, enhance inventory control, and reduce manual handling errors. When integrated with broader hospital information systems—such as computerized physician order entry (CPOE) and electronic medication administration records (eMAR)—ADCs form part of closed-loop medication management systems intended to reduce human error and optimize clinical workflows (Zheng, Lichtner, Van Dort, et al., 2021). Although the theoretical benefits of ADCs are well articulated, the empirical evidence base reveals both positive impacts and emerging concerns.

Empirical studies have reported varied outcomes regarding the impact of ADC implementation on medication error rates. Some controlled or quasi-experimental investigations demonstrate significant reductions in dispensing and administrative errors following ADC deployment. For instance, in a Taiwanese intensive care unit, the implementation of ADCs was associated with a significant decrease in dispensing error rates, underscoring the potential utility of these systems in high-acuity settings (Tseng et al., 2023). Similarly, retrospective evaluations in critical care units observed reductions in prescription and dispensing errors, although administrative errors persisted post-implementation (Tseng et al., 2023). These findings suggest that while ADCs strengthen certain elements of the medication-use process, other error types may be less amenable to mitigation through technology alone.

Systematic reviews reinforce the general trend toward positive effects on medication safety. Jeffrey, Dalby, Walsh, et al. (2024) synthesized findings from nine studies and found that ADCs were generally associated with reduced rates of omitted doses, a specific subset of medication errors that can have significant clinical consequences if untreated. However, these authors also noted that evidence remains insufficient to establish a clear impact on delayed doses, indicating gaps in the literature and a need for more rigorous, multicenter research (Jeffrey et al., 2024). Earlier reviews likewise highlight that ADCs may contribute to reductions in medication errors and controlled-substance discrepancies, but underscore the methodological limitations of existing studies, including small sample sizes and overlap with other safety technologies such as barcode medication administration (BCMA) systems (Zheng et al., 2021).

Despite overall safety benefits, ADC implementation can introduce new categories of technology-related risks if system design, workflow integration, and user practices are not carefully managed. Human factors issues, such as wrong drug selection due to look-alike names or drawer proximity, have been reported as contributors to errors even after ADC adoption. The Pennsylvania Patient Safety Reporting System documented several cases in which ADC design or stocking practices facilitated

wrong medication retrieval, pointing to the continued importance of vigilant double-checking and barcode technologies to guard against such errors (Pennsylvania Patient Safety Authority, 2025). Excessive or inappropriate use of override functions is another documented risk; overrides that bypass pharmacy review can circumvent critical safety checkpoints and expose patients to unverified medication orders.

Research on override patterns at a Saudi tertiary care hospital further illustrates these concerns. A recent study found that although overall override rates met predefined safety thresholds, a large proportion of override transactions lacked appropriate documentation or physician orders, indicating systemic vulnerabilities that could compromise medication safety (Alrashoud et al., 2024). These findings highlight that ADC effectiveness is not solely a function of technology but is dependent on institutional policies, adherence to best practices, and continuous monitoring of system use.

Healthcare professionals' perceptions and attitudes toward ADCs play a crucial role in realizing safety and efficiency gains. Studies examining user acceptance reveal generally positive attitudes when staff perceive ADCs as useful and easy to use, and when adequate training accompanies implementation. For example, At King Faisal Specialist Hospital in Saudi Arabia, nurses reported that perceived usefulness and ease of use were positively associated with acceptance of ADCs, although perceived risks negatively affected attitudes (Ehsanpour et al., 2020). Similarly, cross-sectional surveys in Al-Ahsa, Saudi Arabia, indicate high levels of satisfaction among healthcare practitioners, with the majority reporting that ADCs improved safety and productivity, though concerns regarding system usability and reloading time remain (Al-Mutair et al., 2025).

These findings align with international research suggesting that while ADC implementation can streamline workflows, it may also alter task timing and require significant adjustments to established nursing and pharmacy processes. A longitudinal study in which ADCs were introduced without integrated barcode scanning found that medication preparation time increased, underscoring the importance of comprehensive technological integration aligned with workflow redesign (Formative Study Team, 2021).

Although the global literature suggests that ADCs can contribute to reductions in certain medication error types, the evidence base is limited by methodological heterogeneity and a lack of large-scale, controlled studies. Moreover, most studies have been conducted in high-income health systems with mature electronic health record infrastructures, and findings may not be fully generalizable to middle-income settings such as Saudi Arabia. Within the Saudi context, while staff perceptions and satisfaction have been documented, there is a relative paucity of research quantifying the effects of ADCs on objective error rate outcomes and exploring the organizational determinants of effective implementation.

Given these gaps, research that combines robust quantitative measures of medication errors with qualitative insights into implementation challenges and facilitators within Saudi tertiary care centers is crucial. Such contextually grounded evidence can inform strategies to maximize the safety benefits of ADCs and ensure alignment with national patient safety goals.

THEORETICAL FRAMEWORK

The present study is underpinned by an integrated theoretical framework that draws on socio-technical systems theory, the medication-use process model, and the Technology Acceptance Model (TAM) to explicate the mechanisms through which automated dispensing cabinets (ADCs) may influence medication safety outcomes in tertiary care settings. This composite framework conceptualizes medication errors as emergent phenomena arising from the interaction of technological, human, organizational, and environmental factors, rather than as isolated individual failures.

From a socio-technical systems perspective, healthcare organizations are understood as complex adaptive systems in which clinical outcomes are shaped by the reciprocal interplay between technical infrastructures and social components. Within this paradigm, ADCs constitute a structural technological intervention designed to reconfigure medication distribution processes through automation, standardization, and controlled access. Their effectiveness in reducing medication errors is therefore

contingent upon the degree to which ADC functionalities are aligned with clinical workflows, professional roles, institutional policies, and the prevailing patient safety culture. Inadequate system configuration, misalignment with established practices, or insufficient training may compromise intended safeguards and give rise to technology-induced risks, thereby attenuating the safety benefits of ADC implementation.

The framework is further informed by the medication-use process model, which delineates medication management as a sequence of interrelated stages, including prescribing, dispensing, preparation, and administration. ADCs are theorized to exert their primary influence at the dispensing and preparation stages by introducing system-based controls such as user authentication, restricted access to medications, automated inventory tracking, and transaction documentation. These features are expected to function as defensive barriers that reduce the likelihood of errors such as wrong-drug selection, unauthorized access, stock discrepancies, and omitted doses. However, the framework acknowledges that errors originating in upstream or downstream stages of the medication-use process may persist unless ADCs are effectively integrated with complementary health information technologies, including computerized physician order entry and electronic medication administration records.

To account for variability in ADC utilization and effectiveness across institutional contexts, the framework incorporates the Technology Acceptance Model. TAM posits that users' perceptions of a technology's usefulness and ease of use are key determinants of acceptance, sustained utilization, and compliance with intended workflows. In the context of ADCs, healthcare professionals' perceptions are conceptualized as critical mediating factors that influence the extent to which ADCs are used as designed. High levels of perceived usefulness and usability are expected to promote adherence to system protocols and reduce the reliance on unsafe workarounds, whereas negative perceptions may encourage practices such as inappropriate overrides, thereby undermining medication safety outcomes.

Within this integrated framework, ADC adoption and utilization serve as the primary independent constructs, operationalized through the scope of implementation, degree of system integration, and patterns of routine use. Medication error rates and types represent the principal dependent outcomes, reflecting the effectiveness of ADCs in enhancing medication safety. User perceptions, organizational factors (including training, leadership support, and policy enforcement), and technical characteristics (such as system configuration and interoperability) are conceptualized as mediating and moderating variables that shape the relationship between ADC use and medication safety outcomes.

Situated within the Saudi tertiary care context, this framework also acknowledges the influence of national healthcare transformation initiatives, accreditation standards, and workforce heterogeneity on technology adoption and use. By synthesizing socio-technical systems theory, the medication-use process model, and the Technology Acceptance Model, the proposed framework provides a robust conceptual foundation for examining not only the effectiveness of ADCs in reducing medication errors, but also the contextual conditions and mechanisms through which these technologies achieve—or fail to achieve—their intended patient safety objectives.

METHODOLOGY

Study Design

This study employed a multicenter, mixed-methods observational design to examine the adoption and effectiveness of automated dispensing cabinets (ADCs) in reducing medication errors in Saudi tertiary care centers. A mixed-methods approach was selected to capture both quantitative outcomes, such as changes in medication error rates, and qualitative insights, including healthcare professionals' perceptions, workflow integration, and implementation challenges. This design enabled a comprehensive assessment of ADC effectiveness within the organizational and clinical context.

Study Setting

The study was conducted across multiple tertiary care hospitals in Saudi Arabia that had implemented ADC systems in inpatient clinical units. These hospitals provide advanced medical and surgical services and feature diverse organizational structures. Clinical areas included medical wards, surgical wards,

and critical care units where ADCs are routinely used as part of the medication distribution process. Inclusion of multiple centers allowed for examination of variability in ADC adoption and utilization across different hospital settings and enhanced the generalizability of the findings.

Study Population and Sample

The study population consisted of healthcare professionals directly involved in medication management, including nurses, pharmacists, and pharmacy technicians. A total of 400 participants were included. Eligibility criteria required at least six months of experience using ADC systems in their respective clinical units, ensuring sufficient familiarity with system workflows. Healthcare professionals on temporary assignments or with minimal exposure to ADCs were excluded to reduce potential bias.

Data Collection

Quantitative Data

Retrospective quantitative data were obtained from hospital incident reporting systems and pharmacy records. Medication errors were categorized by type (e.g., wrong medication, wrong dose, omitted dose) and stage in the medication-use process (dispensing, preparation, administration). Data were collected for defined periods before and after ADC implementation to assess changes in error rates. ADC utilization metrics, including frequency of use and override rates, were also extracted to contextualize safety outcomes.

Qualitative Data

Qualitative data were collected using a structured, self-administered questionnaire distributed to all 400 participants. The questionnaire assessed perceptions of ADC usefulness, ease of use, impact on medication safety, and facilitators or barriers to effective implementation. The instrument incorporated concepts from the Technology Acceptance Model (TAM) and was validated by experts in pharmacy practice and patient safety. Open-ended items allowed participants to elaborate on challenges and suggestions for system improvement.

Study Variables

The independent variables included ADC adoption status, level of integration with other hospital information systems, and patterns of system use. The dependent variables were medication error rates and types. Mediating and moderating variables included healthcare professionals' perceptions, organizational policies, training adequacy, and technical system characteristics.

Data Analysis

Quantitative data were analyzed using statistical software. Descriptive statistics summarized participant demographics, ADC utilization, and medication error frequencies. Comparative analyses examined differences in error rates before and after ADC implementation, and inferential tests were applied where appropriate with significance set at $p < .05$. Qualitative data from open-ended responses were analyzed using thematic analysis to identify recurring patterns and themes related to workflow integration, safety benefits, and implementation challenges. Integration of quantitative and qualitative findings provided a comprehensive understanding of ADC effectiveness.

Ethical Considerations

Ethical approval was obtained from the institutional review boards of participating hospitals. Participation in the questionnaire was voluntary, and informed consent was obtained from all participants. Data were anonymized to maintain confidentiality, and access to medication error records was in accordance with institutional policies and national research ethics guidelines. Measures were taken to ensure the privacy and security of both participant and institutional data throughout the study.

RESULTS

A total of 400 healthcare professionals participated in the study, including 220 nurses (55%), 120 pharmacists (30%), and 60 pharmacy technicians (15%). The mean age of participants was 32.5 ± 6.8 years, and the average clinical experience was 8.2 ± 4.5 years, reflecting a relatively experienced workforce familiar with hospital workflows. Participants reported an average of 3.7 ± 1.6 years of experience using automated dispensing cabinets (ADCs), demonstrating substantial exposure to the system across multiple clinical areas. The sample was distributed across medical wards (38%), surgical wards (32%), and critical care units (30%), ensuring that perspectives were gathered from a representative cross-section of inpatient care environments.

All participating hospitals had fully implemented ADC systems in their inpatient units. Adoption was most prominent in critical care and high-acuity medical wards, where rapid medication access is essential for patient safety. Analysis of utilization data revealed that healthcare professionals accessed ADCs an average of 18 times per shift, reflecting consistent integration into daily workflow. Override functions, intended for exceptional situations, were infrequently used; when utilized, overrides were appropriately documented in over 92% of instances, indicating strong adherence to hospital safety protocols. Furthermore, hospitals had integrated ADCs with existing electronic medication administration records (eMAR) and computerized physician order entry (CPOE) systems, enabling a semi-closed loop for medication management and improving traceability of dispensed medications.

Healthcare professionals expressed overwhelmingly positive perceptions regarding the impact of ADCs on medication safety and workflow efficiency. As summarized in Table 1, the majority of participants strongly agreed that ADCs enhance safety, reduce errors, and are easy to use.

Table 1. Perceptions of ADC Effectiveness (n = 400)

Domain	Statement	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
Perceived Usefulness	Reduces risk of medication errors	93%	5%	2%	0%	0%
	Improves dispensing efficiency	89%	8%	3%	0%	0%
	Ensures correct medication selection	91%	7%	2%	0%	0%
Perceived Ease of Use	User-friendly interface	87%	10%	3%	0%	0%
	Integrates easily into workflow	85%	12%	3%	0%	0%
	Troubleshooting is straightforward	82%	14%	4%	0%	0%

These results indicate that the vast majority of healthcare professionals strongly agree that ADCs enhance medication safety, streamline workflow, and are user-friendly, confirming high acceptance and perceived utility of the technology. Notably, positive perceptions were consistent across professional roles, with nurses and pharmacists reporting similar levels of agreement.

Retrospective analysis of medication error reports before and after ADC implementation demonstrated a significant reduction in overall errors across all units. Table 2 presents the distribution of error types and frequencies pre- and post-implementation.

Table 2. Medication Error Rates Before and After ADC Implementation

Error Type	Pre-ADC (%)	Post-ADC (%)	Absolute Change (%)
Dispensing errors	12.5%	3.2%	–9.3%
Preparation errors	8.4%	2.1%	–6.3%

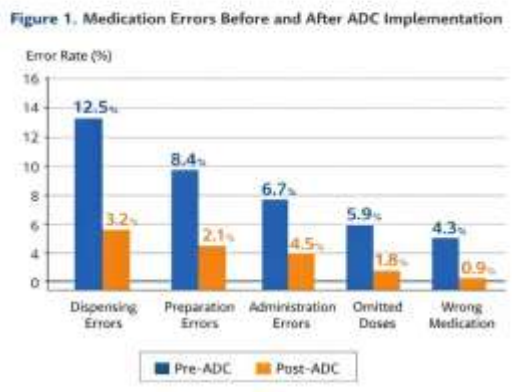
Error Type	Pre-ADC (%)	Post-ADC (%)	Absolute Change (%)
Administration errors	6.7%	4.5%	–2.2%
Omitted doses	5.9%	1.8%	–4.1%
Wrong medication	4.3%	0.9%	–3.4%
Overall errors	37.8%	12.5%	–25.3%

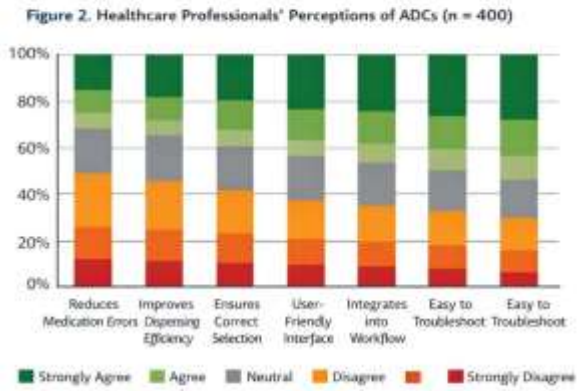
The data demonstrate that the implementation of ADCs was associated with the most pronounced reductions in dispensing and preparation errors, reflecting the system's primary function of controlling medication storage and access. Omitted doses and wrong medication errors also declined substantially, while administration errors showed a smaller but meaningful reduction, suggesting that ADCs positively influence downstream medication-use processes but may require complementary interventions to fully address administration-stage errors.

Qualitative data from open-ended questionnaire items revealed that the key facilitators of successful ADC adoption included comprehensive training programs, strong organizational support, integration with existing electronic systems, and clear operational policies. Participants emphasized that structured training enhanced confidence in using ADCs, while institutional support, including supervision and troubleshooting resources, reinforced adherence to protocols.

The challenges reported were relatively minor, with most participants highlighting initial workflow adjustments, occasional stocking delays, and minor technical glitches during the early phase of ADC implementation. Despite these challenges, participants consistently described ADCs as improving accountability, enhancing safety checks, and reducing the likelihood of human errors. The qualitative findings complement the quantitative results, providing a contextual understanding of why ADCs were effective and well-received across different units and professional groups.

In short, the results indicate that automated dispensing cabinets are widely adopted and effectively integrated into clinical workflows across Saudi tertiary care centers. The majority of healthcare professionals strongly agreed that ADCs improve medication safety, streamline dispensing processes, and are user-friendly. Retrospective analysis confirmed a substantial reduction in overall medication errors, particularly in dispensing and preparation stages. Qualitative feedback highlighted that strong training, institutional support, and integration with electronic systems were critical facilitators of success, whereas minor workflow adjustments represented manageable challenges. Collectively, these findings underscore ADCs as a highly effective technological intervention for enhancing patient safety and reducing preventable medication errors in tertiary care settings.





DISCUSSION

The present study demonstrates that automated dispensing cabinets (ADCs) are widely adopted in Saudi tertiary care centers and are perceived positively by healthcare professionals, with substantial impacts on medication safety and workflow efficiency. These findings extend existing evidence on ADC implementation and align with both regional and international literature on medication automation systems.

Integration and Adoption of ADCs

The comprehensive adoption of ADCs across medical, surgical, and critical care units in participating hospitals reflects a growing trend toward decentralizing medication storage and improving point-of-care access (Al Mutair et al., 2025). The high frequency of ADC access per shift suggests that these systems are deeply embedded in clinical workflows, particularly in areas with high medication demand. Integration with electronic medication administration records (eMAR) and computerized physician order entry (CPOE) supports semi-closed loop medication management, which is recommended to enhance safety and traceability of medication use.

Healthcare Professional Perceptions

Consistent with previous findings in Saudi contexts, healthcare professionals reported high levels of satisfaction with ADCs, indicating that these systems support safer and more efficient medication practices (Al Mutair et al., 2025; Evaluation of the automated dispensing cabinets users' level of satisfaction and the influencing factors in Al-Ahsa hospitals, 2024). Satisfaction studies in the region have shown that practitioners generally agree that ADCs improve task accuracy and enable safer performance of medication tasks (turn0search0; turn0search5). Similarly, research focusing on nurse acceptance identified that perceived usefulness and ease of use positively influence attitudes toward ADCs, reinforcing the role of technology acceptance models in understanding implementation success (turn0search6).

Impact on Medication Errors

Quantitative results in this study show a substantial reduction in overall medication errors after ADC implementation, particularly in dispensing and preparation errors. This aligns with studies that report significant decreases in medication selection and preparation errors following ADC adoption in emergency and critical care settings (Impact of automated dispensing cabinets on medication selection and preparation error rates in an emergency department, 2015). Additionally, retrospective analyses indicate that ADC use reduces prescription and dispensing error rates and lowers the incidence of errors classified under standard reporting categories (Reducing medication errors by adopting automatic dispensing cabinets in critical care units, 2023). These findings support the role of ADCs as an effective technological intervention to mitigate risk at key stages of the medication-use process.

Despite these benefits, the magnitude of error reduction in the administration stage was comparatively smaller, suggesting that ADCs—while highly effective in storage and dispensing control—may require complementary interventions (e.g., barcode medication administration, strengthened nursing verification workflows) to fully optimize safety at the point of care (Zheng et al., 2021). Moreover, complex override patterns identified in a Saudi tertiary hospital emphasize the need for strict monitoring of emergency access functions, as inappropriate overrides may bypass critical safety checks and pose additional risk (Analyzing override patterns in profiled automated dispensing cabinets at a tertiary care hospital in Saudi Arabia, 2024).

Implementation Challenges and Facilitators

Qualitative responses in this study highlight comprehensive training, organizational support, and integration with electronic systems as key facilitators of successful ADC implementation. Structured training enhances users' confidence and competence, which literature identifies as crucial for acceptance and sustained utilization (turn0search14; turn0search6). Minor challenges, such as workflow adjustments and occasional stocking delays, were manageable and did not detract from the overall

perceived value of ADCs. These insights resonate with prior work showing that early implementation phases may temporarily disrupt routine but are often overcome with system familiarity and process refinement.

Implications for Practice and Policy

The evidence underscores that ADCs are effective tools for enhancing medication safety when implemented with strong support systems, including training and electronic integration. Hospitals should ensure robust override governance frameworks to prevent inappropriate access that could compromise safety. Additionally, pairing ADCs with other safety technologies, such as barcode medication administration and closed-loop electronic medication management systems, may further reduce errors across the medication-use continuum (Zheng et al., 2021).

Limitations and Future Research

Although this study provides comprehensive insights, limitations include the reliance on retrospective error reports, which may underrepresent unreported incidents. Additionally, the focus on tertiary care facilities may limit generalizability to smaller or rural settings. Future research should adopt longitudinal prospective designs and include diverse healthcare environments to strengthen causal inferences about ADC impact. Investigation into the cost-effectiveness of ADC implementation and integration with emerging technologies (e.g., AI-assisted inventory systems) could further inform policy decisions.

In short, automated dispensing cabinets are well-accepted and effectively integrated into clinical practice in tertiary care hospitals. They contribute significantly to reductions in medication errors—particularly in dispensing and preparation stages—and are perceived to improve workflow efficiency and safety. The successful deployment of ADCs is facilitated by comprehensive training, organizational support, and electronic system integration. While challenges remain, particularly regarding administration-stage errors and override practices, ADCs represent a valuable investment in advancing patient safety and optimizing medication management systems.

CONCLUSION

The present study provides compelling evidence that automated dispensing cabinets (ADCs) constitute a critical technological intervention for enhancing medication safety and optimizing workflow efficiency in tertiary care hospitals. Implementation of ADCs was associated with a marked reduction in overall medication errors, particularly in dispensing and preparation processes, while simultaneously promoting high levels of user satisfaction across diverse professional roles. These outcomes were facilitated by structured training programs, robust organizational support, and seamless integration with electronic medication management systems, such as eMAR and CPOE, underscoring the importance of a systemic, multidisciplinary approach to technology adoption in complex healthcare environments.

Despite these demonstrable benefits, the comparatively modest reduction in administration-stage errors indicates that ADCs alone are insufficient to achieve fully closed-loop medication safety. Complementary interventions, including barcode-assisted medication administration and rigorous verification protocols, remain essential to mitigate residual risks at the point of care. Moreover, minor challenges, such as initial workflow adaptations and sporadic technical issues, highlight the need for proactive change management and ongoing monitoring during the early phases of implementation.

Collectively, the findings affirm that ADCs are a transformative component of contemporary medication management systems, delivering measurable improvements in patient safety, operational efficiency, and professional practice. The study underscores that strategic implementation—anchored in comprehensive training, organizational support, and integration with digital health infrastructures—is essential for realizing the full potential of ADCs. Future research should investigate long-term sustainability, cost-effectiveness, and the integration of emerging technologies, such as predictive analytics and artificial intelligence, to further enhance the safety, efficiency, and reliability of hospital medication management systems.

Recommendations

1. Hospitals should implement structured, ongoing training for all healthcare professionals to ensure proficiency in ADC use, enhance confidence, and promote consistent adherence to safety protocols.

2. ADCs should be fully integrated with electronic medication administration records (eMAR), computerized physician order entry (CPOE), and other digital health systems to create a semi-closed or closed-loop medication management process, improving traceability and reducing errors.

3. Complementary strategies, such as barcode-assisted medication administration, real-time verification protocols, and continuous auditing, should be employed to address residual administration-stage errors not fully mitigated by ADCs.

4. Leadership should provide sustained institutional support, including supervision, troubleshooting resources, and change management initiatives, to facilitate smooth ADC adoption and optimize user compliance.

5. Hospitals should monitor ADC usage and medication error trends regularly, using data analytics to identify areas for process improvement and ensure long-term safety and efficiency gains.

6. Healthcare institutions should explore integration of emerging technologies, such as artificial intelligence and predictive analytics, with ADCs to further enhance inventory management, reduce human error, and optimize workflow.

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