RESEARCH PAPER

The Impact of Modern Medication Delivery Technologies on Patient Safety and the Efficiency of Medication Practices in Saudi Hospitals

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Abstract

Background: Medication errors remain a major patient-safety concern, while modern hospital medication-delivery systems increasingly integrate barcode medication administration (BCMA), electronic medication administration records (eMAR), automated dispensing cabinets (ADCs), and smart infusion pumps. Although Saudi Arabia has expanded national medication-safety efforts, the combined safety and workflow effects of an integrated medication-technology bundle require rigorous empirical evaluation.

Objective: The objective was to assess whether an integrated medication-delivery technology bundle reduced medication administration errors and improved medication-practice efficiency in Saudi hospitals.

Methods: A controlled before-and-after quasi-experimental study using difference-in-differences analysis was conducted across eight Saudi hospitals, including four intervention hospitals and four comparison hospitals. Data comprised 6,400 direct observations of medication administration and post-implementation survey responses from 248 nurses and pharmacists in intervention hospitals. The intervention bundle included BCMA/eMAR, ADCs, smart infusion pumps with dose-error reduction functionality, and a closed-loop electronic medication workflow. The primary endpoint was medication administration error. Secondary outcomes were potentially harmful errors, omitted or delayed doses, dispensing turnaround time, medication administration time, and staff perceptions. The primary analysis used difference-in-differences estimation and multivariable logistic regression with an intervention-by-post interaction term.

Results: Medication administration errors fell more substantially in intervention hospitals than in comparison hospitals, decreasing from 11.4% to 5.9% versus 11.2% to 10.1%, respectively. The absolute difference-in-differences estimate was -4.44 percentage points (95% CI -7.32 to -1.55; p=0.0026). The adjusted model showed that the intervention-by-post interaction was associated with lower odds of medication administration error (adjusted OR 0.54, 95% CI 0.38-0.76; p<0.001). Omitted or delayed doses decreased by an additional 3.06 percentage points in intervention hospitals relative to comparison hospitals (95% CI -5.43 to -0.69; p=0.011). Dispensing turnaround time improved substantially in intervention hospitals, falling from 44.3 to 27.1 minutes, with an adjusted difference-in-differences of -15.28 minutes. Staff perceptions were generally positive, with safety, efficiency, and usability scores of 84.8, 83.3, and 83.6 out of 100, respectively, although 22.2% reported substantial alert fatigue.

Conclusion: Implementation of the integrated medication-delivery technology bundle was associated with fewer medication administration errors, fewer omitted or delayed doses, and faster medication workflows in Saudi hospitals. These findings support integrated medication technologies as a potentially effective patient-safety strategy when implemented with staff training, usability monitoring, downtime planning, and surveillance for workarounds.

Keywords: medication administration errors; barcode medication administration; automated dispensing cabinets; smart pumps; patient safety; Saudi hospitals

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1. Introduction

Medication-related harm remains a persistent global patient-safety problem. The World Health Organization (WHO) launched the Medication Without Harm challenge to promote system-level action on preventable medication-related harm and identified medication systems and practices as a central safety domain [1,2]. Errors can arise at multiple points in the medication-use process, including prescribing, dispensing, preparation, administration, monitoring, and care transitions. Because administration is the final clinical step before a

medication reaches the patient, safety controls at this stage are especially important.

During the past decade, Saudi Arabia has strengthened national patient-safety infrastructure through initiatives such as the Saudi Patient Safety Center and national medication-error reporting activities [3]. Previous Saudi national work reported gaps in medication-safety practices across hospitals [4]. Subsequent Saudi studies have continued to identify medication errors and under-reporting as important concerns, although reported rates vary by setting, definition, and detection method [5-8]. A 2026 analysis of Ministry of Health reporting data illustrates the scale of current surveillance and shows that many reported errors are intercepted before causing harm [8].

Technology can introduce multiple safety barriers across the medication-use pathway. BCMA/eMAR, ADCs, and smart infusion pumps address different points in the medication-use pathway, including bedside verification, stock control, traceability, and infusion-programming safety. When interoperable, these technologies create a closed-loop medication-management process linking electronic ordering, pharmacy verification, dispensing, administration, and documentation. Previous studies have reported reductions in medication administration errors with barcode systems, improved infusion safety with smart-pump interoperability, and shorter medication turnaround times with closed-loop electronic systems [9-12].

However, digital technology does not remove all medication-safety risk. Workarounds, barcode-scanning deviations, alert fatigue, drug-library bypassing, poor device usability, and downtime can introduce new hazards [13,14]. Evidence from Saudi nurses suggests that smart pump usefulness is influenced by learnability, efficiency, and system support [15]. These concerns indicate that safety gains depend on implementation quality as well as technology acquisition.

This multicenter study evaluated patient-safety outcomes and medication-practice efficiency associated with an integrated medication-delivery technology bundle in Saudi hospitals. The primary hypothesis was that the technology bundle would reduce medication administration errors beyond secular changes observed in comparison hospitals. Secondary hypotheses were that the intervention would reduce omitted/delayed doses, shorten dispensing turnaround and administration time, and be positively perceived by nurses and pharmacists.

2. Methods

2.1 Study Design and Setting

This was a multicenter controlled before-and-after quasi-experimental study using difference-in-differences analysis. The study included eight hospitals from the Central, Western, and Eastern regions of Saudi Arabia, coded H1-H8. Four hospitals were assigned to the intervention group and four to the comparison group. Across hospitals, 400 medication administrations were observed per hospital in each period, producing a total of 6,400 observations. Hospitals were coded as H1-H8 in the analytic dataset.

Figure 1. Study design and analytic flow

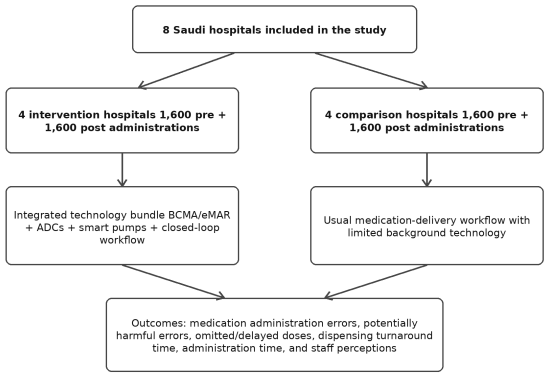

Figure 1. Study design and analytic flow.

2.2 Intervention

The intervention was an integrated medication-delivery technology bundle that included: (1) BCMA linked to eMAR for bedside patient and medication verification; (2) ADCs for controlled ward-level medication access and electronic inventory traceability; (3) smart infusion pumps with dose-error reduction software for intravenous therapies; and (4) a closed-loop electronic workflow linking medication orders, pharmacist verification, dispensing, administration, and documentation. Technology use after implementation reached approximately 91.8% for BCMA, 89.1% for ADC-supported administrations, and 85.6% for smart pumps among intravenous administrations.

Implementation activities included staff training, competency assessment, device super-user support, standardized medication libraries, barcode quality checks, ADC formulary configuration, downtime procedures, and monthly review of overrides and workarounds. Comparison hospitals continued usual medication-delivery practices with limited background adoption of medication technologies.

2.3 Medication Administration Observations

The medication administration episode was the unit of analysis. Observers used a standardized form to capture hospital and clinical context, technology exposure, medication-error outcomes, omitted or delayed doses, dispensing turnaround time, and administration time. Ward type was categorized as medical, surgical, or intensive care, and route was categorized as oral, intravenous, subcutaneous, or intramuscular.

2.4 Outcomes

Primary Outcome

A medication administration error was any observed deviation from correct administration involving medication, dose, route, patient, timing, or procedure. This outcome was coded as a binary variable for each medication administration episode.

Secondary Safety Outcomes

Secondary safety outcomes included potentially harmful medication error and omitted/delayed dose. Potentially harmful medication errors were infrequent, as expected relative to the broader category of all medication errors.

Efficiency Outcomes

Dispensing turnaround time was defined as the number of minutes from medication request or order release to medication availability for administration. Medication administration time represented the nursing workflow time required for each administration episode.

Staff-Reported Outcomes

A 12-item post-implementation questionnaire assessed usability, perceived safety, workflow efficiency, satisfaction, alert fatigue, workarounds, and downtime problems using 1-5 Likert scales. Positive-domain scores were converted to 0-100 scales. Internal consistency for the nine positive items was acceptable, with Cronbach alpha=0.80.

2.5 Sample Size and Data Collection

The analytical sample included 1,600 medication administrations in each group-period cell, yielding 6,400 directly observed administrations. Medication administration data were collected using the standardized observation form described above. A total of 248 nurses and pharmacists from intervention hospitals participated in the post-implementation staff survey. The sample size supported estimation of primary and secondary outcomes and multivariable modeling.

2.6 Statistical Analysis

Categorical variables were summarized using counts and percentages, while continuous variables were summarized using means with standard deviations or medians with interquartile ranges. The primary unadjusted effect was estimated using difference-in-differences (DiD), calculated as the post-pre change in intervention hospitals minus the post-pre change in comparison hospitals. A normal approximation was used to calculate the confidence interval for the DiD in proportions.

Medication administration error was modeled using multivariable logistic regression including period, intervention-by-post interaction, ward, route, high-alert medication status, and hospital fixed effects. The intervention main effect was not interpreted separately because hospital fixed effects captured time-invariant between-hospital differences. Robust standard errors were applied. Continuous efficiency outcomes were analysed using linear regression with the same intervention-by-post framework. Statistical significance was defined as a two-sided p value <0.05.

3. Results

Observation Characteristics

The analysis included 6,400 medication administration episodes: 3,200 from intervention hospitals and 3,200 from comparison hospitals, equally distributed across pre- and post-implementation periods. Medical wards accounted for approximately 43%-47% of observations, surgical wards for 33%-36%, and intensive care units for 19%-23%. Intravenous administrations accounted for approximately 30% of observations. High-alert medications represented 15%-16% of episodes. Observed characteristics were broadly similar across the four study cells (Table 1).

Table 1. Characteristics of observed medication administration episodes.

Characteristic	Intervention Pre	Intervention Post	Comparison Pre	Comparison Post
Number of administrations	1,600	1,600	1,600	1,600
Medical ward, n (%)	689 (43.1)	753 (47.1)	682 (42.6)	737 (46.1)
Surgical ward, n (%)	572 (35.8)	546 (34.1)	552 (34.5)	528 (33.0)
ICU, n (%)	339 (21.2)	301 (18.8)	366 (22.9)	335 (20.9)
Oral route, n (%)	879 (54.9)	879 (54.9)	860 (53.8)	880 (55.0)
Intravenous route, n (%)	482 (30.1)	478 (29.9)	501 (31.3)	484 (30.3)
Subcutaneous route, n (%)	160 (10.0)	166 (10.4)	155 (9.7)	155 (9.7)
Intramuscular route, n (%)	79 (4.9)	77 (4.8)	84 (5.3)	81 (5.1)
High-alert medication, n (%)	261 (16.3)	249 (15.6)	254 (15.9)	245 (15.3)

3.2 Primary Safety Outcome

In intervention hospitals, medication administration errors decreased from 11.4% (182/1,600) before implementation to 5.9% (94/1,600) after implementation. In comparison hospitals, the error rate changed from 11.2% (179/1,600) before implementation to 10.1% (162/1,600) after implementation. The absolute difference-in-differences was -4.44 percentage points (95% CI -7.32 to -1.55; p=0.0026). Multivariable logistic regression showed that the intervention-by-post interaction remained associated with lower odds of medication administration error (adjusted OR 0.54, 95% CI 0.38-0.76; p<0.001).

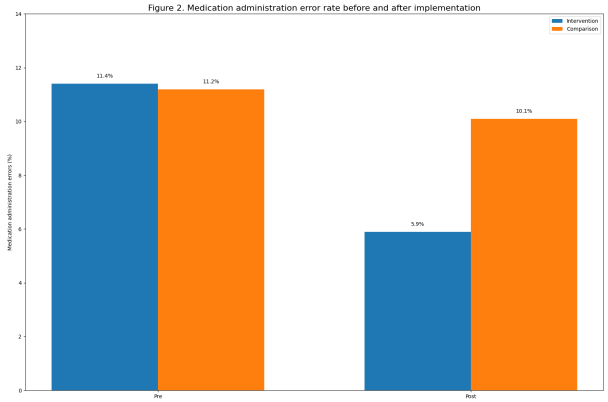

Figure 2. Medication administration error rate before and after implementation. The contrast between groups over time represents the difference-in-differences effect.

3.3 Secondary Safety and Efficiency Outcomes

In intervention hospitals, potentially harmful errors decreased from 8.1 to 2.5 per 1,000 administrations, compared with a decrease from 10.0 to 8.1 per 1,000 in comparison hospitals. Because potentially harmful events were uncommon, the DiD was not statistically significant (-3.75 per 1,000; 95% CI -12.02 to 4.52; p=0.374). Omitted or delayed doses, in contrast, decreased by an additional 3.06 percentage points relative to comparison hospitals (95% CI -5.43 to -0.69; p=0.011).

In intervention hospitals, mean dispensing turnaround time decreased from 44.3 to 27.1 minutes, compared with a decrease from 43.6 to 41.7 minutes in comparison hospitals. The adjusted intervention-by-post effect for dispensing turnaround time was -15.28 minutes (95% CI -16.46 to -14.11; p<0.001). Medication administration time also improved in intervention hospitals, falling from 12.44 to 10.17 minutes compared with 12.26 to 12.13 minutes in comparison hospitals; the adjusted interaction was -2.14 minutes (95% CI -2.42 to -1.87; p<0.001).

Table 2. Primary and secondary outcomes.

Outcome	Intervention Pre	Intervention Post	Comparison Pre	Comparison Post	Difference-in-differences / interaction
Medication administration errors	182 (11.4%)	94 (5.9%)	179 (11.2%)	162 (10.1%)	-4.44 pp (-7.32 to -1.55); p=0.026
Potentially harmful errors	13 (8.1/1000)	4 (2.5/1000)	16 (10.0/1000)	13 (8.1/1000)	-3.75/1000 (-12.02 to 4.52); p=0.374
Omitted/ delayed doses	120 (7.5%)	65 (4.1%)	111 (6.9%)	105 (6.6%)	-3.06 pp (-5.43 to -0.69); p=0.011
Dispensing turnaround, mean min	44.3	27.1	43.6	41.7	Adjusted interaction -15.28 min; p<0.001
Administration time, mean min	12.44	10.17	12.26	12.13	Adjusted interaction -2.14 min; p<0.001

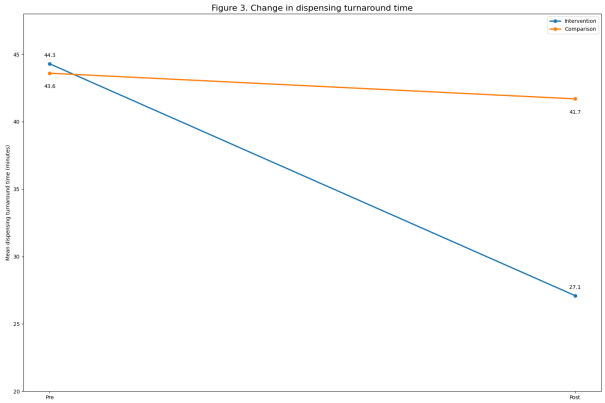

Figure 3. Mean dispensing turnaround time before and after implementation.

3.4 Multivariable model

The multivariable model was consistent with the primary DiD result. The intervention-by-post term was

associated with lower odds of medication administration error, whereas intensive care setting, surgical ward, intravenous route, intramuscular route, and high-alert medication status were associated with higher odds of medication administration error. These estimates reflect adjusted associations within the study and should not be interpreted as causal effects of the individual clinical characteristics.

Table 3. Multivariable logistic regression for medication administration error.

Predictor	Adjusted OR	95% CI	p value
Intervention × post	0.54	0.38-0.76	<0.001
Surgical ward vs medical	1.40	1.15-1.70	<0.001
ICU vs medical	1.76	1.42-2.17	<0.001
IV vs oral route	1.23	1.03-1.49	0.026
Subcutaneous vs oral	0.85	0.62-1.16	0.306
Intramuscular vs oral	1.61	1.14-2.26	0.006
High-alert medication	1.37	1.11-1.70	0.003

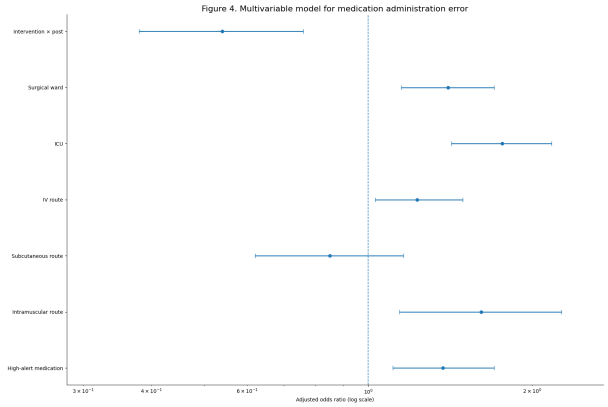

Figure 4. Adjusted odds ratios from the medication administration error model. Values below 1 indicate lower odds relative to the relevant reference category.

3.5 Staff Perceptions and Implementation Barriers

The post-implementation staff survey included 248 respondents, comprising 186 nurses (75.0%) and 62 pharmacists (25.0%). Technology training was completed by 218 respondents (87.9%). Mean perception scores were 84.8/100 for safety, 83.3/100 for efficiency, and 83.6/100 for usability. Overall satisfaction had a mean score of 4.23/5, and 81.9% of respondents selected agree or strongly agree. Most respondents agreed that integrated technology reduced errors (85.1%) and improved workflow (79.8%).

Implementation barriers were still evident. The mean alert-fatigue score was 2.81/5, with 22.2% agreeing or strongly agreeing that alert/alarm fatigue was substantial. Frequent workarounds were reported by 2.8% of respondents, while substantial downtime-related problems were reported by 6.5%. These findings show why medication-safety evaluation should include human factors and workflow measures in addition to error counts.

Table 4. Staff perceptions after implementation (n=248).

Measure	Mean score	Interpretation / proportion
Safety perception score	84.8 / 100	Higher is better
Efficiency perception score	83.3 / 100	Higher is better
Usability score	83.6 / 100	Higher is better
Overall satisfaction	4.23 / 5	81.9% agree/strongly agree
Technology reduces errors	—	85.1% agree/strongly agree
Technology improves workflow	—	79.8% agree/strongly agree
Alert fatigue	2.81 / 5	22.2% agree/strongly agree
Workaround frequency	2.09 / 5	2.8% agree/strongly agree
Downtime problems	2.30 / 5	6.5% agree/strongly agree

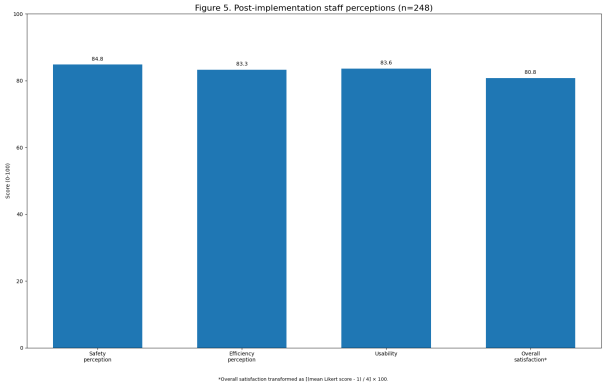

Figure 5. Post-implementation staff perceptions in intervention hospitals.

4. Discussion

Principal Findings

This multicenter study showed that an integrated closed-loop medication-delivery technology bundle was associated with a substantial reduction in medication administration errors beyond the modest secular improvement seen in comparison hospitals. The adjusted interaction OR of 0.54 and the absolute DiD of

-4.44 percentage points both pointed in the same direction, strengthening the internal coherence of the results. Secondary findings also showed lower omitted/delayed dose rates and improved workflow times after implementation.

The study was intentionally designed to evaluate both medication safety and medication-practice efficiency. A technology intervention may reduce some errors while introducing new workflow burdens; therefore, evaluations based only on error counts may miss important implementation effects. The findings showed that safety improvements occurred together with shorter turnaround time and positive staff perceptions. However, alert fatigue remained a meaningful concern, highlighting the need for continuous optimization rather than one-time installation.

Potentially harmful errors decreased in relative terms, but the reduction did not reach statistical significance. Because severe medication events are uncommon, larger samples are typically needed to detect statistically significant effects. Future multicenter studies should consider larger administration samples, longer follow-up, or prospectively adjudicated composite outcomes combining serious near misses and harmful events.

Comparison with Existing Evidence

The direction of these findings is consistent with the broader medication-safety literature. Prior evidence links barcode medication administration with reductions in administration and transcription errors [9]. Smart-pump interoperability may reduce programming-related errors by transferring verified orders to the pump and returning infusion data to the electronic record; one study reported a 16% reduction in medication administration errors after interoperability [10]. Previous evidence has shown shorter time to first dose with closed-loop electronic medication management than with paper-based systems [12].

The Saudi context makes rigorous evaluation of integrated medication technologies especially relevant. National and regional studies show that medication safety remains an active priority in Saudi Arabia, while variation in reporting practices and digital maturity complicates institutional comparisons [4-8]. Recent Saudi evidence suggests that nurses generally perceive smart infusion pumps favorably, although training, usability, and regional differences influence their experience of use [15]. Future empirical work in Saudi hospitals should assess fidelity, overrides, training, interoperability, and digital maturity instead of classifying technology exposure only as present or absent.

The study also reflects an important caution from the literature: technology can fail when clinicians bypass intended workflows. Observational BCMA studies have documented policy deviations and workarounds [13], while multicenter smart-pump observations show that infusion errors can persist despite pump use when drug libraries are bypassed or policies are not followed [14]. These findings support a sociotechnical approach that evaluates devices, software, workflow, staffing, training, and safety culture together.

Implications for Saudi Hospitals

The findings suggest that Saudi hospital leaders should prioritize integrated medication-use ecosystems rather than isolated technology acquisition. BCMA can verify patient and medication identity, but its benefit may be weakened when medication packages are not reliably barcoded. ADCs can improve medication access, but unsafe overrides may bypass pharmacist review. Smart pumps can reduce dose-programming risk, but their safety benefit depends on current drug libraries and staff compliance. Interoperability is central because it connects these technologies and reduces manual transcription.

A practical implementation program should include governance as well as technology, consistent with the published literature. Recommended components include a multidisciplinary medication-technology committee, standardized drug dictionaries and dose limits, high-quality barcode labeling, mandatory training and competency validation, monitoring of scan compliance, ADC overrides and pump-library bypasses, clear downtime workflows, rapid technical support, and regular review of medication errors and near misses. Local hospital medication-safety improvement can be linked with national surveillance through the Saudi Patient Safety Center and reporting infrastructure [3,8].

Potential efficiency gains should also be assessed financially in future empirical research. Faster turnaround may reduce nursing time spent locating medications and making urgent pharmacy calls, whereas ADCs and smart pumps introduce capital, maintenance, licensing, cybersecurity, and training costs. A full economic evaluation could estimate cost per medication error prevented, staff time saved, inventory savings, and avoided adverse drug event costs.

Strengths and Limitations

The study was strengthened by its multicenter comparison group, balanced pre/post observations, direct medication-administration assessment, efficiency outcomes, staff usability measures, and difference-in-differences analysis.

Limitations include the non-randomized design and potential residual confounding. Because only one pre-implementation period was available, the difference-in-differences parallel-trends assumption could not be directly evaluated, and the inclusion of only eight hospitals limits cluster-level inference. Because the intervention was delivered as a bundle, the effects of individual technologies cannot be separated. The study did not assess long-term sustainability; potentially harmful errors were uncommon; and the staff survey was post-implementation only, preventing assessment of within-person attitude changes. Observer effects, under-detection of errors, staffing changes, concurrent quality-improvement initiatives, and baseline digital-maturity differences may also have influenced the estimated effects.

Conclusion

In this multicenter study, implementation of an integrated closed-loop medication-delivery technology bundle was associated with fewer medication administration errors, fewer omitted or delayed doses, and shorter medication workflow times in Saudi hospitals. Staff generally perceived the technologies positively, but alert fatigue and sociotechnical risks remained implementation concerns. These findings support integrated medication-delivery technologies as part of a broader patient-safety strategy combining implementation fidelity, workflow monitoring, staff training, human-factors evaluation, and continuous quality improvement

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