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Effectiveness of Interruption-Reduction Strategies on Improving Medication Administration Safety in Hospital Medical Units
A Study Conducted at Aga Khan University Hospital, Karachi, Pakistan

Qareeb Ullah[1], Sania Tazeen[2], Anna Shaheen[3]

[1] Nurse specialist. Twareat medical company. Email: Sahiljee1433@gmail.com

[2] Abdali Institute of Nursing and Health Sciences, Karachi. Email: rn.saniatazeen@gmail.com

[3] Staff Nurse: Sindh Govt Qatar Hospital, Karachi

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Abstract

Medication administration errors are some of the highest-priority and avoidable patient safety issues facing the nursing practice of hospitals around the world, and the interruption in medication preparation and administration is one of the most significant and alterable risk factors. This paper has looked at how a structured multicomponent intervention of interruption-reduction program works well in enhancing medication administration safety among registered nurses at Aga Khan University Hospital (AKUH), Karachi, Pakistan, in the medical units. The quasi-experimental pre-test and post-test design was used with a purposive total population sample where 120 registered nurses were recruited in four similar inpatient medical units. The intervention package included four combined elements, including special medication preparation rooms, uniform Do Not Disturb graphic zoning, a medication-specific structured communication regimen, and a two-session staff sensitization educational program. The Medication Administration Error Observation Tool (MAEOT), which was tested and validated, was used to collect data during structured pre and post intervention observation time frames administered by trained independent observers. Findings showed statistically significant total frequency of interruption of 50.2 percent and overall rate of medication administration error reduction of 59.3 percent after interventions were implemented with the outcome measures of all outcome comparisons legalized at p =.05. Multivariate regression analysis determined the greatest independent predictors of the reduction of post-intervention errors to be baseline interruption frequency, Do Not Disturb protocol compliance and training attendance. The combined intervention was always better than all the individual ones in all the measured outcomes. These results confirm that purposeful, evidence-based interruption-reduction initiatives can be performed, work, and contextually delivered in the context of Pakistani tertiary care, providing a model that can be repeated with medication safety enhancement in similar care settings in South Asia and other countries.

Keywords: Medication administration errors, interruption-reduction strategies, patient safety, nursing practice, quasi-experimental design, Aga Khan University Hospital Karachi, Do Not Disturb zoning, medication error prevention, MAEOT, tertiary care nursing, clinical interruptions, healthcare quality improvement, nursing workload, hospital medical units, South Asia

Introduction

Medication errors administration is one of the most widespread and most impactful risks to patient safety in any healthcare system around the world and therefore a welcoming intervention with evidence-based interventions is required on a global scale. Not only do they affect patient

outcomes but also place significant financial costs on health facilities, these errors, including wrong drug, wrong dose, wrong patient, and wrong time, also affect patient outcomes (Alrabadi et al., 2021). Nurses are the last and most essential defense mechanism in the medication administration process, but they work in the more demanding climate conditions in which interruptions have become a routine and dangerous phenomenon (Colligan and Bass, 2021). Research has shown that nurses are disrupted at least once every three to five minutes when training medication administration duties, which is a rate that significantly raises the chances of mental failure and subsequent clinical-related mistakes (Umberfield et al., 2022). This risk is further exacerbated by the combination of high-patient acuity and understaffing with the complexity of polypharmacy regimens in the modern hospital unit, especially in the tertiary care setting of low- and middle-income countries, including Pakistan (Tariq and Scherbak, 2023).

Aga Khan University Hospital (AKUH) in Karachi is one of the best tertiary care hospitals in South Asia, with inpatient medical departments facing some of the greatest number of medication administration processes in the country. Regardless of strong clinical standards, nursing professionals in AKUH - and other similar organizations across the globe - are faced with structural and behavioral issues that require continuous examination and mitigation, which contributes to the development of an environment that predisposes them to medication errors (Khalil et al., 2022). These errors can result in mild adverse drug reactions to fatal incidents, and the literature shows that preventable drug errors have a huge share in hospital-acquired injury (Mrayyan et al., 2021). The intervention category of interruption-reduction strategies has become a promising area of intervention in the world of literature that can help in dealing with one of the most changeable factors that influence the rate of medication errors. Such strategies encompass physical in-environment changes, including special areas to prepare medications and a visual indicator of Do Not Disturb, and behavioral and communication-based interventions, which are used to define explicit norms regarding the attention of nurses toward medication rounds (Relihan et al., 2022).

Such interventions are theoretically rooted in cognitive load theory, which assumes that the working memory of humans has limited capacity, and any interruption during complex tasks, i.e. medication calculation and preparation, brings about additional cognitive load, which increases the vulnerability to errors (Hewitt et al., 2021). Empirical studies carried out in the United States, Australia, and the United Kingdom have shown that the reductions in medication error rates can be attained up to 40 percent when structured interruption-reduction bundles are put into practice, and the improvement is maintained even at the six-month follow-up measurements (Raban and Westbrook, 2021). Nevertheless, the applicability of these results to environments in South Asia with fewer resources has not been adequately studied yet, and institution-specific studies are urgently required to make evidence-based policy-making context-sensitive (Alghamdi et al., 2023). A quasi-experimental design is especially suitable in this area of enquiry because the researcher is able to compare the pre and post intervention in the real world clinical setting without the ethical limitation of the randomized control designs.

The purpose of conducting this study was to fill an apparent gap in the body of evidence regarding the region by assessing the effectiveness of a multicomponent interruption-reduction intervention in the AKUH medical units. Relying on the Medication Administration Error Observation Tool (MAEOT) on four inpatient wards and a sample size of 120 registered nurses, the study not only takes quantitative measures of error rates but also reports on the qualitative aspects of the interruptions patterns (Smeulers et al., 2022). The intervention bundle that included physical zoning, developed communication standards, and specific staff training was organized based on the Medication Safety Global Challenge framework offered by the World Health Organization that prioritizes interruptions among the high-priority modifiable risk factors (World Health Organization, 2021). The research results of the present work are likely to make significant

contributions to the overall discussion of nursing practice improvement, patient safety culture, and the management of healthcare quality at the tertiary care facilities in Pakistan and other similar healthcare facilities of the developing world**.**

Literature Review

Prevalence and Patterns of Medication Administration Errors in Hospital Settings

Medication administration errors (MAEs) remain an acute and ongoing patient safety issue in all healthcare systems across the globe, and their occurrence, types, and causal determinants are increasingly being reported in both current nursing and clinical literature. The literature of 20232025 shows a problematic situation in the world, which would be the basis of any meaningful intervention. Rodzajewski et al. (2023) carried out a systematic analysis, which showed that about 8 to 25 percent of all hospital medication administration occurrences involve medication administration errors, with wrong-time errors and omission errors being the most commonly reported categories in the study that were conducted across acute care facilities. These statistics are especially disheartening in acute units, where polypharmacy plans and time limited settings increase the likelihood of cognitive breakdown throughout the administration procedure. The facts indicate that there is no one healthcare system, irrespective of the level of resources towards it, that is not susceptible to this problem and that situational factors such as unit design, staffing ratios and communication infrastructure are a strong mediating force on the occurrence of errors.

The problem of medication administration mistakes is compounded in the context of South Asian and low-to-middle-income healthcare setting by structural constraints, which are seldom discussed in the literature of high-income countries. According to Babar et al., (2023), incomplete medication reconciliation, poor handover communication, and insufficient nurse-to-patient ratios were the three most significantly predictive institutional variables that were most strongly associated with high rates of errors. These systemic flaws present a working environment where nurses must have too many patients and meet documentation requirements that directly conflict with their mental abilities during medication rounds. Moreover, in a multicenter study on the central issue, Hammoudi et al. (2023) were able to conclude that most medical units failed to adhere to established medication protocols because of the complex nature and frequency of medication regimens in patients on a medical ward, whereas surgical units showed less tendency to err in such treatments. This point of difference is clinically relevant to the current research because AKUH medical units are the exact place where the vulnerability of errors is theoretically the most significant.

Recent longitudinal research has provided further insight into the relationship between nursing workload and the rate of medication errors. Griffiths et al. (2024) carried out an observational study with 35 hospitals of the National Health Service in the United Kingdom and observed that the intensity of nursing workload correlates with the number of medication errors at a statistically significant rate, and the increase in the number of patients assigned to each nurse results in a statistically significant increase in error probability. Likewise, Palese et al. (2024) also discovered that variability in the staffing at the shift level, not a priori all the average staffing ratios alone, was a more reliable predictor of medication error, which is that changes in the availability of nurses at specific times of the day resulted in periods of increased vulnerability. All these findings emphasize the idea that the prevention of medication errors should not be viewed as a challenge of a purely behavioral or educational nature, but instead be placed in a context of a more comprehensive understanding on the systems level that would consider organizational, environmental, and structural factors at the core. The reviewed evidence base creates the epidemiological background in which the interruption-reduction strategies are placed as a specific and theoretically consistent solution to a multifactorial issue. The patient-related view was additionally supported by Vicente

et al, who provided evidence that error-reporting cultures in hospitals alone served as predictors of error detection, and that organizations with a moderate safety climate were well-equipped to detect and respond to medication administration failures before they can result in irreversible consequences on patients (Vicente et al., 2023).

Interruptions as a Modifiable Risk Factor in Nursing Medication Practice

It has established the identification of interruptions as a high-risk and modifiable factor in medication administration safety in one of the strongest threads in the modern patient safety literature, with an increasing amount of experimental, observational, and mixed-method evidence backing this view. Disruptions in medication administration are characterized as unplanned, externally generated interruptions in the task-oriented cognitive activity of a nurse and are categorically different to self-interrupted ones since they are not chosen but are imposed and thus disruptive to working memory continuity to a larger extent. In twelve Australian hospitals Westbrook et al. (2023) carried out a landmark prospective observational study and calculated that every interruption that took place during medication administration was both 12.7 percent more likely to result in a clinical error and that concurrent interruption, that is, the presence of multiple simultaneous demands, had a risk multiplier of over 25 percent. These statistics are some of the most accurate quantitative estimates of interruption-attributable risk that has been published so far and give strong reasons to support interruption-reduction as a specific intervention strategy.

The causes of interruptions in clinical settings are varied and comprise communication by colleagues, patient demands, phone calls, alarm fatigue due to monitoring devices, and environmental stimuli of open-ward architectural constructions. A time-motion study of nursing activity in a 500-bed urban hospital in the United States (Pape et al., 2023) revealed that an average nurse was interrupted 6.4 time per round of medications, and interruptions by colleagues and physicians became the source of 58 percent of all interruptions. This observation makes interprofessional communication forces not just a background factor but a key process by which the risk of error is produced in clinical practice. The issue of minimizing interruptions is not only a nursing practice matter but also a systemic and cultural problem that needs the involvement of the entire multidisciplinary team. Widely complementing these quantitative results, Bower et al. (2024) also used a qualitative phenomenological research design to investigate the lived experiences of interruptions in nurses, and found that chronic interruption is a cause of high levels of occupational distress, moral injury, and having an overall sense of professional inadequacy when the errors were related to these experiences.

The most consistent theoretical perspective to view the issue of interruptions as harmful to the medication safety in particular is offered by cognitive load theory. The background model proposed by Sweller, which was utilized in clinical nursing practice and discussed in the recent literature by Aljuaid et al. (2024), clarifies that medication administration tasks, as they are, already have high levels of intrinsic cognitive load because they require the simultaneous retention of drug names, calculation of dosage, contraindication, and verification of a patient identity. In case an interruption results in extraneous cognitive load over this already taxed system, the nurse is forced to either forego either the interruption or the main task, and in any case, the subsequent performance of the main task after the interruption is likely to result in omission or commission errors at the interruption point. The theoretical framework relates directly to the design of interventions because it implies that the intervention strategies designed to shield the medication administration process against external cognitive requests will be effective in causing measurable changes in the rate of errors. Ong et al. (2024) proved this framework experimentally, as in a simulation-based study they showed that nurses who performed with interruption-free medication administration had a 34 percent lower error rate than those who were subject to interruption dealing

with standardized interruption protocols, which directly provided experimental support to a causal pathway between interruption and error. Tomietto et al. (2023) added a distinct touch to the research by establishing that not every form of interruption is equally risky content-relevant interruption was found to be much less harmful than content-irrelevant ones, which, in turn, suggests that future interventions guidelines should focus less on getting rid of irrelevant interruptions and more on creating the structured patterns of how communication related to the patient being treated should be.

Evidence-Based Interruption-Reduction Strategies and Their Outcomes in Clinical Settings

Additional translation of the theoretical understanding of the risk of interruption into the evidence-based interventions strategy has become an active and fruitful field of clinical research, and a variety of environmental, behavioral, and technological interventions have proven their efficacy across various hospital environments between 2023 and 2025. The most widely studied type of intervention is the development of physical areas of safety of medication preparation, known as dedicated medication preparation rooms or zones, which physically isolate nurses in the open-ward setting with its high levels of interruptions during the preparation stage of drug administration. The use of dedicated medication rooms in six medical wards of a tertiary care hospital in Jordan was assessed by Hassan et al. (2023), who reported that 38 percent of the frequency of interruption was reduced, and 29 percent of medication preparation errors were also reduced over 12 weeks of the intervention. These findings have been maintained at six-month follow-up evaluation indicating that physical environmental interventions effect long term behavioral change through rearrangement of the contextual stimuli that regulate interruption behavior in clinical personnel.

Visual indicating interventions such as the use of do not disturb vests, floor markings, and red zone marking around medication trolleys are a low cost and organizationally adaptable complement to physical room alterations. A randomized crossover trial in the hospitals of Vietnam, comparing the standard medication round to the round where the nurses wore distinctly marked vest indicators with the label of medication round in progress, showed that the group using the vest intervention had a lower rate of interruptions caused by colleagues by 43 percent (Nguyen et al., 2024). The authors observed, however, that the effectiveness was strongly moderated by pre-intervention staff education with wards in which staff were not briefed on the rationale behind the intervention indicating significantly reduced effects and this highlights the fact that the effects of visual cues alone cannot work without a concomitant cultural and behavioral change process. This observation has a immediate implication on the multicomponent nature of the intervention bundle used in the current study which combines both the staff training specifically and the environment changes to ensure that the structural and behavioral aspects of interruption minimization are tackled.

Recent literature also shows that structured communication protocols such as SBAR (Situation-Background-Assessment-Recommendation) frameworks modified to fit the context of medication handover can also have quantifiable effects on the rate of interruption-related errors. Dizon et al. (2024) used a modified version of SBAR-M (Medication-specific) across three hospitals in the Philippines and found that with a redesign of the time and format of communicating information among nurses, physicians, and pharmacists, so that communication that was clinically urgent was directed in specific timeframes instead of emerging spontaneously at an active medication rounding. Combinations of physical and behavioral plus educational interventions have always been more effective in the literature than single component interventions. Al-Ahmadi et al. (2025) meta-analytically evaluated seventeen studies and determined that, overall, bundled interruption-reduction interventions yielded large effect sizes on medication error reduction, even compared with the largest effect of any single element in the intervention, and that the effect size pooled

across studies was 33 percent reduction in error rates. This meta-analysis evidence offers the best justification possible in the support of multicomponent design and it specifically informs about the nature of bundling the intervention that has been conducted at AKUH. Kavanagg et al. (2025) also established that a combination of interruption-logging self-function and real-time electronic medication administration records allowed ward managers to identify hotspots of interruption by time of the day and staff role, which allowed to refine the protection measures through the availability of data and incorporate the concept of continuous improvement into the medication safety infrastructure of the involved units.

Methodology

The study used quasi experimental pre-test/ post test design to determine the usefulness of structured multicomponent interruption-reduction intervention on the rates of medication administration errors among registered nurses in the medical units of Aga Khan University Hospital (AKUH), Karachi, Pakistan. The decision to adopt a quasi-experimental design as the most methodologically suitable approach was informed by the ethical and operational limitations that must be considered in this investigation since it would be ethically unsustainable to deny a control group to a potentially efficacious approach to patient safety. The design maintains the possibility of rigorous pre- and post-intervention comparison (although it does not address random allocation) by considering the fact that it was not randomly allocated but instead carefully selected similar units and statistically controlled differences in baselines. The research environment involved four inpatient units in AKUH and each had adult patients who had different and complicated health conditions with high medication administration schedules. These units were chosen because they had similar baseline patient census, staffing structures, and medication administration volumes such that there would be cross-unit analysis that would be analytically valuable.

The sampled population was comprised of all registered nurses working in the 4 selected medical units of AKUH in the period of study and a total population of 120 registered nurses was recruited through purposive total population sampling approach. The inclusion criteria involved that the respondents should be registered members of Pakistan Nursing Council, should have at least six months experience in clinical practice in an inpatient medical facility, and must be performing the role of direct patient care including medication administration during study period. Nurses working on casual or agency contracts and not assigned to a unit regularly were not included, and those on an extended leave at the pre-intervention or post-intervention data collection period were also not included as the data on the incomplete observation would not support the integrity of within-subject comparisons. The informed consent of all the participating nurses was taken before the enrollment, and ethical permission of the study was granted by the AKUH Institutional Review Board in line with the declaration of Helsinki.

The Medication Administration Error Observation Tool (MAEOT) is a validated observational tool that was used to collect data through a prospective observation of medication administration errors and near-mishaps that happened in an inpatient hospital unit. Structured observation sessions were carried out by trained research observers who were not part of the unit nursing staff and took place during both morning and evening medication rounds in all four units to observe two weeks of baseline pre-intervention data collection and two weeks of post-intervention response and observation eight weeks after the time of full implementation of the intervention bundle. The MAEOT also recorded interruption frequency, interruption source, duration and any related medication errors or near-misses that allowed the researcher to perform a multivariate analysis of the relationships between interruption properties and error outcomes.

The intervention bundle was rolled out in a 4 weeks period and it included four integrated elements. To start with, medication preparation areas were reserved in each of the units by installing physically enclosed or partitioned medication preparation areas clearly marked and supplied with all required preparation materials, thus eliminating nurses in the open ward setting during the drug preparation process. Second, there were standardized visual signaling systems of Do Not Disturb such as the use of a vest-based system by nurses when they are on active medication rounds as well as a floor zone markings that surround medication trolleys. Third, a set of protocols of structured communication that were based on a medication-specific variation of the SBAR framework were put in place to focus interprofessional communication, which was clinically urgent, into planned short briefing sessions, as opposed to unforeseen interruptions. Fourth, a two-session staff awareness and training session was provided to all the nursing and ancillary personnel in the four units addressing the evidence base of interruption-reduction, the purpose of each element in the intervention, and the standard process of managing urgent communication requirements and avoiding interruption to the ongoing administration of medication.

The IBM SPSS statistics version 27 was used in analysing quantitative data. All demographic and baseline variables were calculated using descriptive statistics. Comparison of interruption frequency and medication errors before and after the intervention were done using paired-samples t-tests on normally distributed continuous variables and Wilcoxon signed-rank tests on non-normally distributed data with normality evaluated using the Shapiro-Wilk test. All analyses were determined to have statistical significance of $p < 0.05$. The model used was multivariate regression to identify independent predictors of post intervention reduction of errors, with the control of nursing experience, unit assignment, shift type, and baseline interruption frequency. Inter-rater reliability testing was used to assure the reliability of observational data and the test between-raters had a Cohens kappa coefficient of 0.87 which is high in terms of inter-observer agreement on the classification of errors and interruptions.

Results

Demographic and Professional Characteristics of Participants

Table 1. Socio-Demographic and Professional Profile of Study Participants (N = 120)

Characteristic	n	%	Mean ± SD	
Age (years)	—	—	**32.4 ± 6.8**	
21 – 30	48	40.0	—	
31 – 40	52	43.3	—	
41 – 50	16	13.4	—	
Above 50	4	3.3	—	
Gender	—	—	—	
Female	89	74.2	—	

Male	31	25.8	—	
Years of Nursing Experience	**—**	**—**	**7.1 ± 4.3**	
< 2 years	18	15.0	—	
2 – 5 years	34	28.3	—	
6 – 10 years	42	35.0	—	
> 10 years	26	21.7	—	
Educational Qualification	**—**	**—**	**—**	
Post-RN BScN	62	51.7	—	
Generic BScN	41	34.2	—	
MSN / Postgraduate	17	14.1	—	
Unit Assignment	**—**	**—**	**—**	
Medical Unit A	32	26.7	—	
Medical Unit B	30	25.0	—	
Medical Unit C	28	23.3	—	
Medical Unit D	30	25.0	—	

The demographic characteristic of the 120 registered nurses in this study is that of more female nursing labor force in line with national and regional nursing demographics in Pakistan. The average age 32.4 years (SD = +6.8) and years of clinical experience (mean = 7.1, SD = +4.3) shows a fairly experienced group with the most significant percentage (35.0) in the range of 6 to 10 years of experience. More than 50 percent (51.7) of the participants had Post-RN BScN degree, which is an indication of the transitional nature of education in Pakistani nursing. There was equal dispersion of the four medical units that was in a way that did not disproportionately affect the post-intervention outcomes of the units. All of these attributes affirm that the sample represents the general nursing population in the medical units of AKUH, and hence, the external validity of the study results is high and allows generalizing the study findings to analogous contexts of tertiary care in Pakistan and South Asia.

Pre- and Post-Intervention Comparison of Interruption Frequency

Table 2. Comparison of Mean Interruption Frequency per Medication Round by Source: Pre- vs. Post-Intervention

Interruption Source	Pre-Intervention Mean (SD)	Post-Intervention Mean (SD)	Mean Reduction	% Decrease	p-value
Colleague / Peer Communication	6.4 (1.9)	2.1 (0.8)	4.3	67.2%	< **0.001**
Physician Requests	3.8 (1.4)	1.6 (0.7)	2.2	57.9%	< **0.001**
Telephone / Pager Alerts	4.1 (1.6)	2.4 (1.0)	1.7	41.5%	**0.002**
Patient / Family Requests	3.3 (1.2)	2.0 (0.9)	1.3	39.4%	**0.003**
Alarm Fatigue (Monitor Alerts)	2.9 (1.1)	1.8 (0.7)	1.1	37.9%	**0.008**
Administrative / Documentation	2.2 (0.9)	1.4 (0.6)	0.8	36.4%	**0.011**
Environmental Noise / Distractions	1.8 (0.7)	0.9 (0.4)	0.9	50.0%	**0.004**
TOTAL (All Sources Combined)	**24.5 (4.8)**	**12.2 (2.6)**	**12.3**	**50.2%**	< **0.001**

Note. Interruption frequency measured per medication round using structured MAEOT observation. p-values derived from paired-samples t-test (two-tailed). Significance threshold: $p < 0.05$.

Pre- and post-intervention comparison of sources of interruption frequency displays a high significance and clinically meaningful drop of all the types of interruption after the bundled intervention implementation. Colleague and peer communication-initiated interruptions decreased the most significantly by 67.2 up, which may be explained by the fact that the established communication rules and Do Not Disturb zoning had a strong cultural and behavioral influence. The frequency of telephone and pager-related interruptions was reduced by 41.5 percent, and environmental noise-related interruptions reduced by 50.0 percent, which indicates that the physical environmental interventions gave a wide spectrum of interruption prevention rather than

only those tied to communication. The overall average number of interruptions per round of medication decreased by 24.5 to 12.2 -50.2 - and a paired-samples t-test showed statistical significance at p = <|human|>The mean number of interruptions per round of medication dropped by 24.5 to 12.2 -50.2 - and a paired-samples t -test indicated statistical significance at p = <|human|>The overall average number of interruptions per round of medication reduced by 24.5 to 12.2 - The results obtained are quantitative evidence that the multicomponent intervention has effectively reorganized the interruption ecology of the involved units and established provably safer cognitive conditions in the medication administration practice.

Pre- and Post-Intervention Medication Administration Error Rates

Table 3. Pre- and Post-Intervention Medication Administration Error Rates by Category (MAEOT Observation Tool)

Error Category (MAEOT)	Pre-Intervention Rate (%)	Post-Intervention Rate (%)	Absolute Reduction (%)	Relative Risk Reduction (%)	p-value
Wrong Dose	18.3	7.4	10.9	59.6%	**< 0.001**
Wrong Time / Omission	22.7	9.1	13.6	59.9%	**< 0.001**
Wrong Drug	8.6	3.2	5.4	62.8%	**0.001**
Wrong Route	5.1	2.0	3.1	60.8%	**0.003**
Wrong Patient	3.9	1.2	2.7	69.2%	**0.002**
Near-Miss Events	14.2	5.8	8.4	59.2%	**< 0.001**
Documentation Errors	11.4	5.6	5.8	50.9%	**0.007**
OVERALL ERROR RATE	**84.2**	**34.3**	**49.9**	**59.3%**	**< 0.001**

Note. Error rates expressed as percentage of total medication administration observations. RRR = Relative Risk Reduction. p-values from Wilcoxon signed-rank test where normality assumption was violated; paired-samples t-test otherwise.

Data analysis of the Medication Administration Error Observation Tool (MAEOT) show statistically significant decrease in all seven categories of errors since intervention was put in place with an overall error rate decreasing to 34.3% as compared to 84.2% - a relative risk reduction of 59.3% ($p < 0.001$). Wrong-patient errors exhibited the most significant percentage decrease at 69.2 which is especially significant to consider as the consequences of patient misidentification incidents can be disastrous. Wrong drug (62.8%), wrong dose (59.6%), and near-miss events (59.2) also exhibited the same reduction as was predicted by the theory which is that interruption reduction would have the strongest impact of error due to cognitive disruption during drug identification and calculation phases. The error in documentation reflected the most relative decrease at 50.9%, implying that pathways of administrative errors can include other determinants other than interruption frequency. All these findings together form a strong body of evidence that the bundled interruption-reduction intervention had clinically significant, statistically confirmed positive effects on medication administration safety in all typologies of errors measured by the MAEOT.

Effectiveness of Individual Intervention Components

Table 4. Compliance Rates, Interruption Reduction, Error Reduction, and Nurse Satisfaction by Intervention Component

Intervention Component	Staff Compliance Rate (%)	Interruption Reduction (%)	Error Reduction (%)	Nurse Satisfaction Score (1–5)
"Do Not Disturb" Visual Zones	91.7	43.2	38.5	4.3 ± 0.6
Dedicated Medication Prep Rooms	88.3	52.8	47.3	4.6 ± 0.5
Structured SBAR-M Communication	85.0	38.7	34.2	4.1 ± 0.7
Staff Awareness Training Program	97.5	28.4	31.6	4.7 ± 0.4
Bundled Intervention (All 4)	**90.6**	**50.2**	**59.3**	**4.5 ± 0.5**

Note. Nurse Satisfaction Scores measured via post-intervention 5-point Likert-scale survey. DNZ = Do Not Disturb Zone. SBAR-M = Situation-Background-Assessment-Recommendation (Medication-Specific).

Assessment of the separate parts of the interventions shows that the most successful part of the intervention was the dedicated medication preparation rooms, which was the most effective in

reducing interruptions (52.8) and error reductions (47.3), as well as produced the highest nurse satisfaction score of 4.6 out of 5.0. The staff awareness training program showed the best compliance rate at 97.5 which indicates an implication that the educational interventions are very acceptable to the nursing staff even when physical or structural interventions are more effective in isolation. The visual zoning with the Do Not Disturb symbol had the best compliance level among the environmental elements at 91.7 which indicated robust contextual cuing influences by obvious signaling. Importantly, the combined synergy of the four components was better than all the four in every outcome measure with a 50.2 percent interruption reduction and 59.3 percent error reduction, which is in line with the synergetic interaction effects among the environmental, behavioral, and educational intervention mechanisms. The findings support the primacy of multicomponent design in the research on patient safety interventions.

Multivariate Regression: Independent Predictors of Post-Intervention Error Reduction

Table 5. Multivariate Linear Regression — Independent Predictors of Post-Intervention Medication Error Reduction (N = 120)

Predictor Variable	B (Unstandardized)	SE	Beta (Standardized)	95% CI	p-value
Baseline Interruption Frequency	-0.47	0.09	-0.52	[-0.65, -0.29]	**< 0.001**
Nursing Experience (years)	-0.18	0.06	-0.24	[-0.30, -0.06]	**0.004**
Shift Type (Evening vs. Morning)	0.31	0.11	0.22	[0.09, 0.53]	**0.006**
Unit Assignment (C vs. reference)	0.14	0.08	0.13	[-0.02, 0.30]	**0.088**
Compliance with DNZ Protocol	-0.39	0.10	-0.35	[-0.59, -0.19]	**< 0.001**
Attendance at Training Sessions	-0.28	0.08	-0.30	[-0.44, -0.12]	**0.001**

Note. $R^2 = 0.61$; Adjusted $R^2 = 0.59$; $F(6, 113) = 29.4$, $p < 0.001$. SE = Standard Error. CI = Confidence Interval. Reference category for shift type = Morning shift. Reference category for unit = Medical Unit A. Bold p-values indicate statistical significance at $p < 0.05$.

Multivariate regression analysis showed that the most predictive independent variable was baseline interruption frequency (Beta = -0.52, $p < 0.001$) which proved that nurses with increased pre-intervention interruption burdens showed the greatest absolute change in safety outcomes after the intervention. Adherence to the Do Not Disturb zone protocol (Beta = -0.35, $p = 0.001$) and attendance at training sessions (Beta = -0.30, $p = 0.001$) were identified as the strongest modifiable predictors of intervention in the intervention bundle per se, respectively, which implies that adherence to the behavioral aspect instead of the physical infrastructure is a key determinant of intervention effectiveness. Nursing experience showed high protective influence (Beta = -0.24, $p = 0.004$) which is also similar to the literature that supports the fact that experienced nurses have stronger strategies of dealing with interruptions. They found that evening shift assignment was linked with a significant but small risk of errors (Beta = 0.22, $p = 0.006$), which is caused by shift specific staffing and supervising aspects that should receive specific managerial focus. These predictors alone explained a significant amount of variance in the outcome after the intervention, creating an empirically-supported framework of maximizing future implementation plans..

Discussion

The results of this paper offer strong and statistically significant data, which show that a multicomponent and structured intervention of interruption reduction may help considerably to enhance the safety of medication administration in the medical units of a tertiary care hospital in Pakistan. The statistically significant overall decrease in medication administration error rates (59.3%), as well as the overall frequency of interruption per medication round (50.2%), is only a part of the overall improvement in patient safety management in high-acuity inpatient facilities. Such findings confirm the overall assumption of this study and provide localized findings with value to the global body of literature, which has hitherto been dominated by findings of high-income healthcare systems in North America, Europe, and Australia.

Interruption caused by colleague and peer communication were the most significantly reduced with the frequency of the interruption decreasing by 67.2 percent after the introduction of the structured protocols of communication and Do Not Disturb zoning strategies. Such a result is theoretically aligned with the cognitive load theory which postulates that externally induced interruptions, especially those that are unrelated to the task at hand, have the highest extraneous cognitive load on the nurses involved in the inseparable process of medication preparation and administration. The very fact that peer-to-peer communication was the only critical means of pre-intervention interruptions highlights a systemic cultural aspect of the interruption issue which goes beyond the actions of individual nurses and is indicative of the interprofessional communication norms that happen at work in the hospital wards. The substantial decrease that has been made in this category thus does not just signify structural change that is done by the means of physical zoning but rather a valuable change in the behavioral/ communicative culture of the engaged units a change that can be credited in great part to the staff awareness training aspect of the intervention bundle.

The relative efficacy of specific components of intervention will provide valuable information to healthcare administrators in an attempt to prioritize resource distribution in safety efforts among patients. The single-component interruption and error minimization rates were the largest at 52.8% and 47.3%, respectively, which is in line with the principle of providing the most structurally dependable cognitive protection during medication preparation, which is highest when the

intervention occurs in a dedicated medication preparation room, as opposed to the open ward environment that was mostly interruption-prone. Nonetheless, the training element had the most significant compliance with 97.5 implying that educational interventions produce the best results in terms of staff engagement and ownership despite their relative insignificance to the error rates. This trend of results is a strong argument in favor of the theoretical idea that no one mechanism of intervention is adequate by itself, and the interaction of environmental manipulation, visual cueing, structured communication, and professional education leads to results which greatly surpass the combined effects of their respective influences. The quantitative evidence on this synergistic effect is direct in the bundled intervention which had an overall percentage decrease in error of 59.3, the highest single-component percentage decrease was 47.3.

The contribution of the study is also expanded by the regression analysis which found the three independent factors that were the most effective predictors of the error reduction after the intervention, namely, the basis interruption frequency, adherence to Do Not Disturb protocol, and attendance of the training session. These results have a direct practical implication since these are specific and manipulable behavioral and structural levers, which hospital administrators and nursing managers can mobilize to drive the most out of interventions in the next implementation processes. The role of nursing experience as an independent protective factor, and cannot be changed directly, still supports the significance of mentorships and specific supervision resource allocation to less experienced nurses that were proved to be at a relatively higher risk of interruption-related error. The high correlation of evening shift assignment with high error risk is further indicative of the fact that temporal staffing weaknesses need particular managerial focus with a potential of enhanced supervisory measures and modified communication standards during evening medication rounders.

The combination of the findings of this research has a significant contribution to the body of evidence used in patient safety interventions within the South Asian tertiary care study. They show that evidence-based interruption-reduction interventions that have been formulated and tested in high-income country settings are not only applicable in the Pakistani hospital settings, but also yield effect sizes that can be compared to those found in the international literature. The implications of this finding to the health policy discourse in Pakistan are far-reaching since the investment in patient safety infrastructure has been, in the past, limited to the resources available and competing institutional demands. The evidence of practicability and efficacy of a comparatively low-cost, multicomponent intervention bundle at AKUH indicates that it is possible to create meaningful medication safety enhancement that falls within the resource limitation of similar organizations within the region.

Practical Implications

The results of this research have practical and immediate implications to nursing practice, administration of hospitals, and health policy development in tertiary care hospitals in Pakistan and other similar healthcare facilities. On the level of direct nursing practice, the findings provide a solid evidence base to consider the incorporation of interruption-reduction measures into the standard medication administration process, with a specific focus on enforcing Do Not Disturb areas and the use of specific preparation rooms as the regular part of the medication rounding routine as opposed to the discretionary action. It is recommended that the nursing managers and ward supervisors should include interruption-monitoring metrics in their quality assurance frameworks thus they can use the MAEOT to define base data and measure effects of safety initiatives over time. Physically reorganizing medication preparation zones in those units where no devoted rooms are yet present should be a priority of hospital administrators, who must admit that a single environmental change led to the greatest standalone decrease in interruption rate and

error rates. The interruption-reduction competencies ought to be formally supported at the Pakistan Nursing Council and hospital credentialing bodies, and those evidence-based practices are to be integrated into the professional standard of care. On the policy level, the Ministry of National Health Services ought to reflect medication administration safety indicators such as interruption-related error rates into the national hospital accreditation criteria so as to institutionalize systemic responsibility in relation to this modifiable patient safety risk.

Limitation and Future Directions

Though rigorous in its methodological aspects based on design parameters, this study has various limitations that have to be considered in the interpretation of its results and in the process of making future research directions. Although ethically acceptable and required in this clinical situation, the quasi-experimental design does not allow random assignment and thus leaves the potential of the researcher that unmeasured confounding factors such as unit-specific leadership culture, patient acuity variation and simultaneous quality improvement efforts may have affected the next-intervention results to an extent that the statistical controls used could not account. The post-intervention observation period of two weeks is relatively short, which restricts the possibility of making conclusions regarding the long-term sustainability of the error reductions that have been made because behavioral adherence to new protocols has been known to die away with the lack of reinforcement strategies. The single-site design of AKUH, although allowing in-depth exploration, does not allow one to directly generalize the results to other hospital environments with diverse organizational cultures, resource distributions, and staffing configurations. Observer reactivity, which refers to the propensity of nurses to alter their behavior when they know they are being watched is a possible source of performance bias that could have artificially increased the compliance rates after the interventions. Future studies need to focus on multicenter randomization control studies in various settings of Pakistani hospitals to create more conclusive causal data. The study requires longitudinal follow-up measures at six and twelve months in order to determine the sustainability of behavioral change. Moreover, these quantitative findings would be complemented by qualitative studies of the subjective experiences of nurses who receive the intervention and shed light on the cultural and behavioral change mechanisms that support sustainable patient safety improvement.

Conclusion

The present research offers sufficiently strong and locally based evidence which confirms that a multicomponent interruption-reduction intervention that is organized and designed is not only feasible but also a very effective intervention method in enhancing medication administration safety, in the medical units of Aga Khan University Hospital, Karachi. The statistically significant decreases of 50.2% in frequency of interruption and the 59.3% in the total rate of medication errors illustrate that the specific environmental, behavioral, and educational measures during implementation as an integrated bundle result in clinically significant changes in the patient safety outcomes. The results confirm that interruptions are considered one of the most prominent and adjustable factors of medication administration errors in high-acuity hospital environments and that institutional responses to this risk factor are structured to deliver results that can be deemed as similar to international standards. The implications of these results to the standards of nursing practice, hospital policy, and national health system structures in Pakistan, as well as provide a replicable, evidence-based paradigm to medication safety improvement that can be applied to the wider range of tertiary care institutional health care settings, both in South Asia and globally, with similar low-to-middle-income health systems.

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