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Development and Evaluation of a Multifaceted Intervention Program for Preventing Medication Administration Errors by Nurses

Won Hee Sim, PhD, RN

Objective: This study aimed to develop and evaluate a multifaceted intervention program based on the Systems Engineering Initiatives for Patient Safety (SEIPS) model to prevent medication administration errors (MAEs) by nurses in an adult general ward of a comprehensive hospital in Seoul, South Korea.

Methods: The program was developed using the Analysis, Design, Development, Implementation, Evaluation (ADDIE) model with a 3-round Delphi survey conducted with 16 experts. Strategies were categorized under the SEIPS model and finalized into a program with 9 domains and 21 interventions. A pretest-posttest design with 73 nurses (36 experimental, 37 control) evaluated the program's effectiveness in a tertiary care hospital in Seoul, South Korea. Surveys on patient safety culture, medication safety practices, and error rates were analyzed before and after a 3-month intervention using double-difference and time-series methods.

Results: The DID analysis demonstrated significant improvements in patient safety culture perception (0.42, $P < 0.001$) and medication safety compliance (0.53, $P < 0.001$), with large effect sizes ($d = 1.07$ and $d = 1.41$, respectively). However, changes in self-reported medication error rates between groups were not statistically significant ($P = 0.555$), likely due to the short intervention period.

Conclusion: The program improved patient safety awareness and medication safety compliance, validating its approach. This study highlights the importance of theoretically based interventions and suggests shifting from solely nurse education to addressing systemic issues for medication safety.

Key Words: medication errors, patient safety, nurses, safety management, program development

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Medication errors, defined as "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the healthcare professional, patient, or consumer,"[1] are a critical concern in patient safety. These errors can extend hospital stays, cause permanent disability or death, and increase health care costs significantly.[2] Each year, medication errors in the United States result in 7000 to 9000 deaths, unreported adverse reactions in hundreds of thousands of patients, and over $40 billion in health care costs, affecting more than 7 million individuals and emphasizing the critical need for systemic improvements in medication safety.[3] In South Korea, a total of 63,088 patient safety incidents were reported through the Patient Safety Reporting and Learning System by December 2022, with medication errors accounting for 43.3% of all incidents in 2022.[4] Given the preventable nature of medication errors and their substantial physical, mental, and financial harm, addressing these errors is a critical task in clinical settings.[5,6]

Single interventions are limited in reducing and preventing medication errors, but multifaceted interventions incorporating multiple strategies are more successful.[7–9] Recent international studies emphasize the effectiveness of system-based multifaceted interventions that consider interactions of 5 key elements (person, task, technology, environment, organization) within the work system, as outlined by the SEIPS (systems engineering initiatives for patient safety) model.[10,11]

In South Korea, research has predominantly focused on single interventions, with limited studies on multifaceted interventions considering interactions within the medication administration system. Thus, the goal of this study was to (1) develop a nurse-targeted medication administration error prevention program based on the SEIPS model,[12] (2) verify its validity by applying it in an adult general ward, assessing nurses' awareness of patient safety culture and medication safety compliance, as well as analyzing self-reported medication error data, both before and after the program's implementation.

The conceptual framework of the study is illustrated in Figure. 1.

METHODS

This study was conducted in 2 phases. The first phase was a methodological study to develop a medication administration error prevention program for clinical nurses. The second phase was a quasi-experimental study with a nonequivalent control group pretest-posttest design to verify the program's validity.

Program Development

To develop a program to prevent medication administration errors among clinical nurses, the widely used ADDIE model by Seels and Richey[13] was selected. This model comprises 5 stages: Analysis, Design, Development,

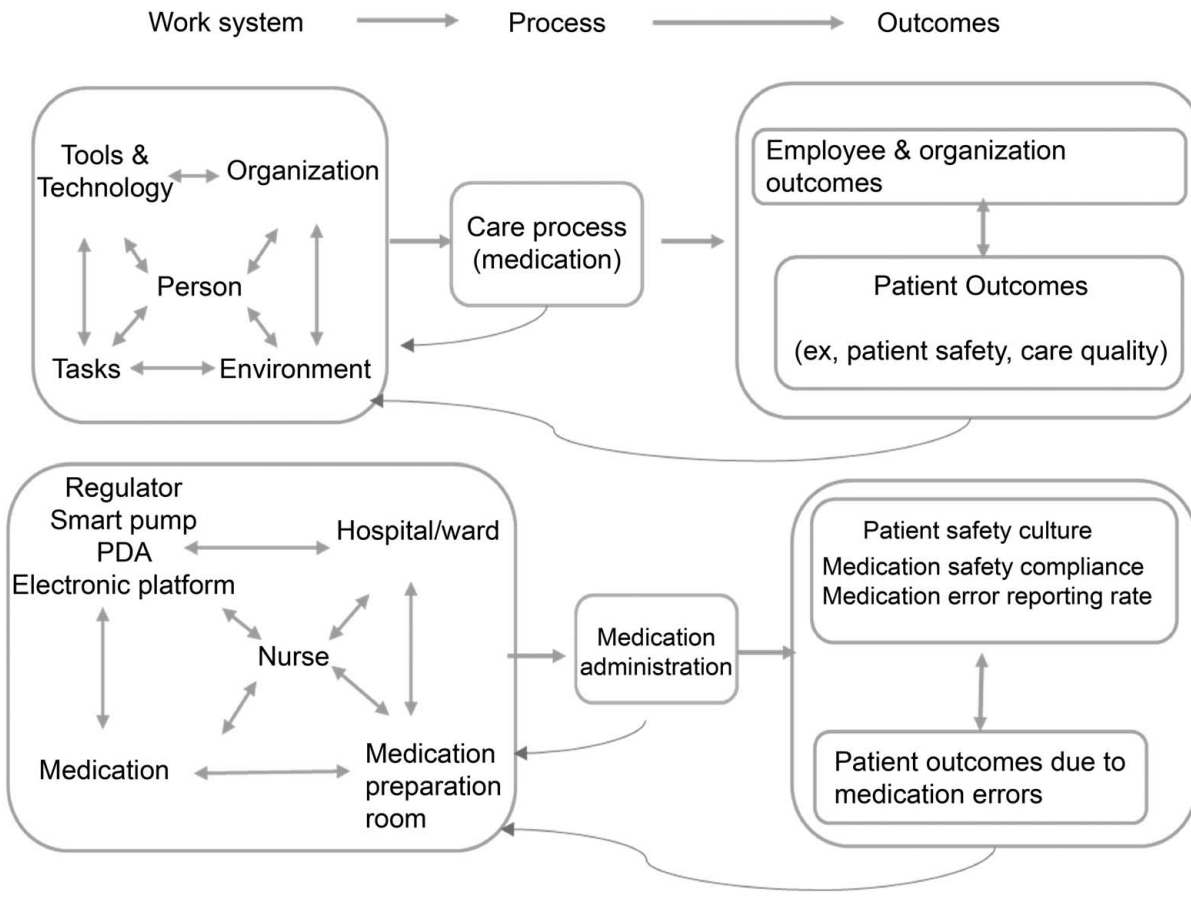

FIGURE 1. Conceptual framework of the study based on SEIPS model.[12]

Implementation, and Evaluation. The research procedure is outlined in Figure 2.

Analysis

A literature search was conducted using multiple databases, including PubMed, Cochrane Library, Google Scholar, and RISS, focusing on articles published between 2006 and 2023. The search terms included both keywords and MeSH headings, along with synonyms and related terms, to ensure a comprehensive review. These terms were structured based on the PICO criteria, targeting clinical nurses as participants, interventions on medication safety, and outcomes such as patient safety culture, medication safety compliance, or medication error reporting. The review aimed to address key questions on intervention methods and their effectiveness in preventing medication administration errors in acute care hospitals. Consequently, 12 relevant articles were selected, encompassing both single and multifaceted interventions that aligned with the 5 elements of the SEIPS model. The search strategies are outlined in Appendix 1, Supplemental Digital Content 1, http://links.lww.com/JPS/A696.

Design

(1) The objective was to improve clinical nurses' awareness of medication safety culture and their compliance with medication safety practices, thereby reducing medication safety incidents. (2) Evaluation tools included the translated "Hospital Survey on Patient Safety Culture version 2.0" (HSOPSC 2.0)[14] to assess patient safety culture awareness. The survey includes 34 items: 1 item on the frequency of patient safety event reporting, 1 item on the overall ward safety grade, and 32 items across 10 domains, rated on a 5-point Likert scale. Higher scores indicate greater awareness of patient safety culture, with negatively worded items reverse-scored. The tool's reliability, as measured by Cronbach alpha, ranged from 0.67 to 0.89 in Sorra and colleagues' study. In addition, the medication safety compliance tool developed by Hayes et al[15] and adapted by Jeong[16] was used. This scale consists of 11 items, with higher scores indicating greater compliance with safety practices. In this study, the tool was adapted to focus specifically on medication safety and was renamed the "Medication Safety Compliance Scale." The tool's reliability, as measured by Cronbach alpha, was 0.85 during development and 0.79 in Jeong's study. The self-reporting rate of medication errors was calculated as the ratio of self-reported error cases from the hospital's patient safety reporting system to the total number of prescriptions issued in the study ward (March 2020-March 2024). This rate was expressed as the number of errors per 100,000 prescriptions. (3) Medication error intervention items were identified through a literature review and a 2-round Delphi survey[17] during the design phase. The survey involved 16 experts,

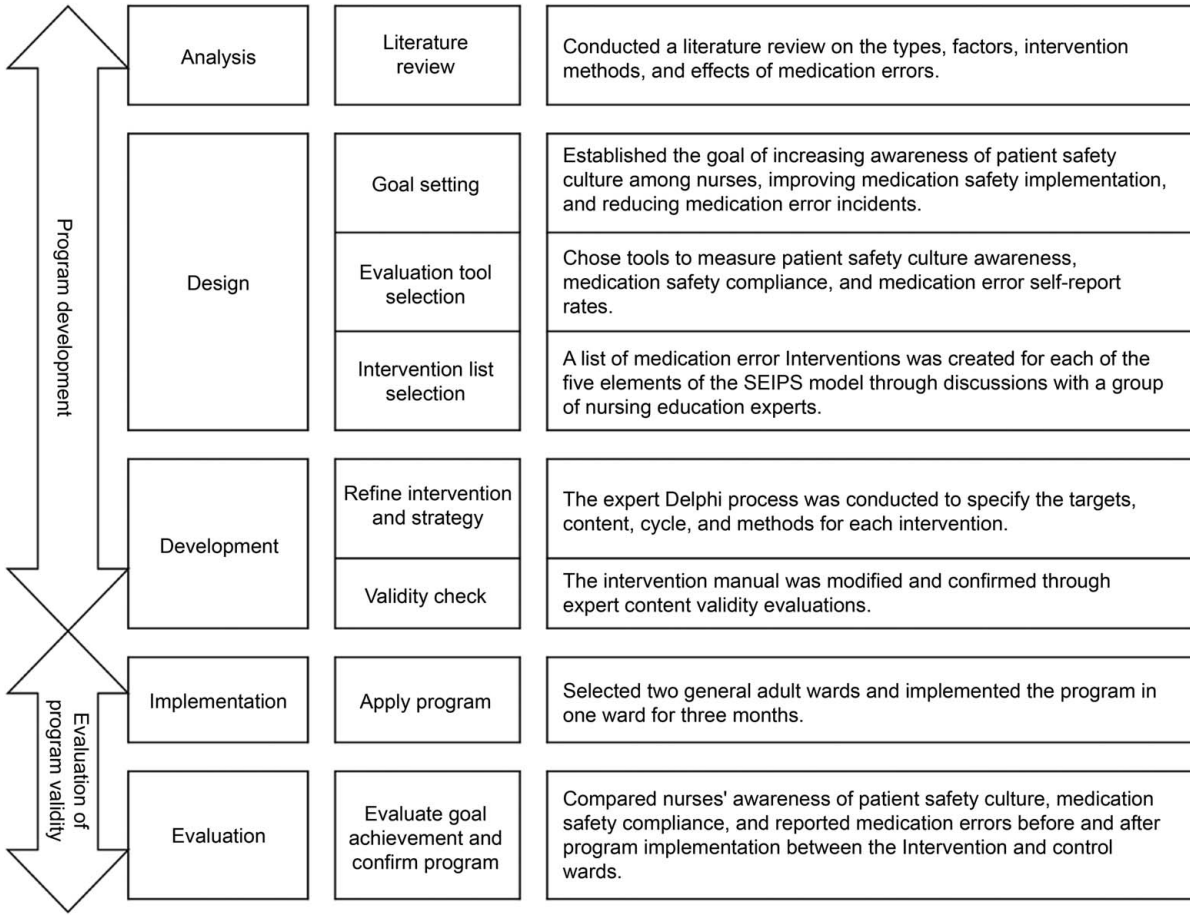

FIGURE 2. Research procedure.

slightly exceeding Hodgkinson et al's[18] recommendation of a group size of 10 to 15 for reliable results. Participants included 11 head nurses and 5 nurse educators, selected based on specific criteria: a minimum of 7 years of clinical experience, at least 1 year of patient safety consultation experience, and, for educators, more than 2 years of experience in medication safety education. Experts were recruited via email invitations, followed by a detailed explanation of the study and a consent process. In round 1, experts identified medication error prevention interventions from the literature that could be applied in the ward. In round 2, the identified interventions were categorized into system dimensions, including environmental, technological, human, task, and organizational levels.

Development

The development stage involves specifying the intervention manual. A draft manual was developed through a third-round Delphi survey with experts, detailing the specific methods, target population, intervention provider, and frequency for each intervention.

The draft manual was reviewed and validated by the expert group. The content relevance by Lynn[19] was examined, and the intervention program was revised and finalized based on their feedback.

Evaluation of Program Validity

Research Design

A quasi-experimental design with a nonequivalent control group pretest-posttest was used to investigate nurses' awareness of patient safety culture, medication safety compliance, and self-reported medication error rates before and after the program's application.

Data Collection Method

Two study wards were conveniently selected from among 30 adult general wards in a tertiary care hospital located in Seoul, South Korea. One ward was assigned to the experimental group and the other to the control group. A recruitment notice was posted on the bulletin boards of the selected wards, inviting participants. A total of 40 nurses from each of the experimental and control wards requested an explanation from the researcher. After receiving the explanation, consent forms were obtained from 36 nurses in the experimental group and 37 nurses in the control group, resulting in a total of 73 final participants.

Research instruments were (1) participant characteristics assessed using four items (total work experience in the hospital, current ward experience, hospital working hours, and level of patient interaction), (2) patient safety culture awareness measured using the translated "Hospital Survey on Patient Safety Culture version 2.0" from the

AHRQ, consisting of 34 items across 10 dimensions on a 5-point Likert scale. Higher scores indicate greater awareness. Cronbach alpha in this study was 0.90, and medication safety compliance was assessed using a tool developed by Hayes et al[15] and adapted by Jeong Soo Kyung.[16] It includes 11 items, with higher scores indicating better compliance. Cronbach alpha in this study was 0.72, (3) self-report rate of medication errors was calculated as the proportion of self-reported medication errors from the total prescriptions in the study wards from March 2020 to March 2024, converted into the error rate per 100,000 prescriptions.

Data collection procedures are as follows: (1) patient safety culture awareness and medication safety compliance surveys conducted twice: presurvey (November 24-30, 2023) and post-survey (February 26-29, 2024) in both program-applied and nonapplied wards. (2) Self-report rate of medication errors collected from the patient safety reporting program for March 2020 to March 2024, with personal identifiers removed. The data included medication classification, administration route, date and time, prescription type, nurse experience, error type, harm degree, and posterror interventions.

Data were analyzed using statistical software (IBM SPSS Statistics Ver. 29): (1) descriptive statistics: frequencies, percentages, means, and SDs for participant characteristics and self-report rates; (2) homogeneity test: using Fisher exact test and Pearson χ^2 test; (3) difference-in-differences analysis: for patient safety culture awareness and medication safety compliance preprogram and postprogram; (4) interrupted time series regression analysis: for self-report rates of medication errors between wards; (5) reliability testing: using Cronbach alpha coefficients for each tool.

Ethical Considerations

The study was approved by the SMG-SNU Hospital Ethical Review Board in 2023 (IRB NO:20-2023-75) before the study was initiated. All participants provided written consent.

RESULT

Program Development

Analysis Phase

(1) Literature review: a total of 12 studies were reviewed, focusing on interventions to improve medication administration errors by clinical nurses in acute care hospitals. Seven were single-intervention studies, while 5 involved multifaceted interventions. (2) Key findings from single-intervention studies: interventions included double-checking,[20,21] interruption management,[8,22,23] education and training,[18,24–29] barcode implementation,[18,23–27,30,31] smart pumps,[24,31,32] comparisons of functional/charge/self-medication methods,[18,33] and development of checklists and protocols.[21,23,28,29,34,35] (3) Key findings from multifaceted interventions: combinations included simulation education-risk management,[25–27] medication education-drug information,[9] education-risk management-barcode use,[8] and double checking-barcode-patient involvement-storage changes-interruption management-error classification system,[36] among others.

Design Phase

(1) Delphi process: conducted in 2 rounds. Participants included 11, 4, and 1 master's degree, bachelor's degree, and doctoral degree holders, respectively. The group consisted of 5 dedicated nursing educators and 11 head nurses, with an average clinical experience of 17.4 ± 6.9 years (Table 1). (2) Initial intervention list: developed through literature review, consisting of 4 categories (prescription, dispensing, nursing professionalism, culture/environment), 10 factors, 19 subfactors, and 29 intervention items. The first Delphi round identified low validity scores (CVI = 0.69) for interventions related to physician prescription and pharmacist dispensing errors, leading to their exclusion (Table 2). (3) SEIPS model categories: the second Delphi round categorized interventions according to the SEIPS model elements (task, person, environment, technology, organization) and included standardization, education, case sharing, protocol refinement, rounding, campaigns, platform development, newsletter posting, monitoring, and counseling (Table 3).

TABLE 1. General Characteristics of Participants in the Delphi Study for Developing a Medication Error Prevention Program (n = 16)

Characteristics	n (%) or $M \pm SD$
Age (y)	41.4 ± 6.9
Sex	
Female	16 (100.0)
Education	
Bachelor's degree	4 (25.0)
Master's degree	11 (68.8)
Doctoral degree	1 (6.3)
Position	
Nurse educator	5 (31.3)
Unit manager	11(68.8)
Clinical experience (y)	17.4 ± 6.9

Development Phase

(1) Draft manual: created through the third Delphi round, detailing specific interventions for each SEIPS element. The manual included methods, targets, implementing entities, and intervention cycles. (2) Key interventions: included revising protocols for common errors, monthly and online training, patient safety rounds, drug information platform, emergency consultation lines, customized training modules, simulation and feedback, and patient/caregiver involvement campaigns. (3) Revised interventions: based on further discussions, interventions such as "organizing and posting information on major drug mixing solvents" and "prohibition of urgent medication administration before delivery time when physicians order additional medications" were revised for better validity. The final MAEP(medication administration error prevention) program consists of 9 domains and 21 intervention items, as summarized in Table 4.

Evaluation of Program Validity

Patient Safety Culture Awareness and Medication Safety Compliance

Survey response rate and participant characteristics:

The response rates for the pretest and posttest were 36 (90.0%) for the experimental group and 37 (92.5%) for the control group. There were no significant differences between the groups in total work experience ($P = 0.78$), ward work experience ($P = 0.51$), weekly working hours ($P = 0.56$), and direct patient interaction ($P > 0.99$). Participant characteristics are shown in Table 5.

Preintervention dependent variables of the intervention and control groups: the preintervention mean scores for patient safety culture awareness showed no significant

TABLE 2. First Delphi Result on Initial Interventions for Developing a Medication Error Prevention Program Based on the Literature Review

Category	Factor	Detailed factor	Intervention content	M ± SD	CVI
Prescription related	Vague prescription	Ambiguous prescription set	Avoid prescriptions that require dosage calculations	3.8 ± 1.3	0.69
			Harmonization of drug order and text prescription usage	3.8 ± 1.3	0.69
		Text prescription	Clear unit indication when prescribing insulin MSII	3.8 ± 1.3	0.69
		Oral prescription in nonemergency cases	Prohibition of oral order in unauthorized situations	3.8 ± 1.3	0.69
			Forming a prescription management committee	3.8 ± 1.3	0.69
	Incorrect medication usage	Mixed solvent prescription error	Master registration of standard prescriptions for major mixed solvents	3.8 ± 1.3	0.69
			Standard prescription offline posting and HIS loading	3.8 ± 1.3	0.69
Dispensing related	Inaccurate prescription dispensing	Medicines that are not divided into single doses (syrup)	One-time distribution of syrup from the pharmacy department	3.8 ± 1.3	0.69
	Dispensing information not included	S-TPN (central/peripheral) classification	TPN label notation classification	3.8 ± 1.3	0.69
		Lack of information on single-administration drugs	Single administration drug information HIS installed	3.8 ± 1.3	0.69
(Administration-related) Nursing expertise	Lack of knowledge.	Lack of knowledge related to medication	Establishment of emergency consultation window regarding medication administration	4.6 ± 0.7	0.88
			Sharing and education of major medication error cases	4.8 ± 0.6	0.94
			Customized medication training for new/transferred/experienced nurses	4.8 ± 0.6	0.94
		Inaccurate dosage calculation	Standardization of major drug calculation cosign	4.9 ± 0.3	1.00
			MSII Insulin control method training	4.9 ± 0.3	1.00
	Lack of skills	Absence of standard protocol for controlling regulator	Standardization of regulator operation method	4.9 ± 0.3	1.00
			Prepare a checklist	4.7 ± 0.5	1.00
		Inaccurate medication labeling	Standardize medication labeling methods	4.7 ± 0.6	0.94
			Campaign and education to check dispensing labels before administration	4.6 ± 0.7	0.88
	Attitude problem	Hasty medication preparation	Distinguishing between confusing drug labeling (painkillers, narcotic supplies)	4.9 ± 0.3	1.00
		Lack of confirmation of the 5Rs of medication administration	Production and attachment of pen-type insulin identification stickers	4.8 ± 0.6	0.94
			Training on how to confirm HIS medication omissions	4.8 ± 0.6	0.94
		Insufficient confirmation of drug side effects	Training on how to record and confirm allergies on HIS	4.9 ± 0.3	1.00
Culture/Environment	Medication culture	Insufficient confirmation of medication status upon handover	Reinforcement of patient safety rounding (preparation of checklist)	4.6 ± 0.7	0.88
		A culture of hasty medication administration for additional prescription drugs	Campaign to avoid hasty medication administration for additional prescriptions	4.8 ± 0.6	0.94
	Medication environment	Environment where it is difficult to concentrate on medication preparation and medication administration	Campaign to prevent interference with nurses preparing medication	4.9 ± 0.3	1.00
		Lack of patient/guardian participation related to medication	Patient/guardian participation campaign on medication safety	4.9 ± 0.3	1.00
	Lack of manager awareness of patient safety incidents	Lack of patient safety incident counseling protocols	SPARK coaching method training	4.7 ± 0.5	1.00
			Coaching applied when counseling employees on medication errors	4.6 ± 0.7	0.88

CVI indicates content validity index.

TABLE 3. Intervention Lists for 5 Categories Based on the SEIPS Model for Medication Error Prevention After the Second Delphi

SEIPS model elements	Category	Intervention method	Intervention content	M ± SD	CVI
Task	Protocol reorganization	Standardization of medication protocol	Standardization of regulator operation sequence	4.8 ± 0.4	1.00
			Standardization of cosign method for major high-risk drugs	4.6 ± 0.6	0.94
			Standardization of medication preparation procedures (mixed drug labeling, medication labeling)	4.9 ± 0.3	0.94
		Standardization of patient safety rounding protocols	Confirm patient safety through quick rounding, including infusion pump and regulator setting when handing over.	4.6 ± 0.6	0.94
		Standardization of medication safety counseling protocol	Counselling on improvement strategies through FMEA in case of medication safety accidents	4.6 ± 0.6	0.94
Person	Target education	Safe medication procedure training (regulator, blood transfusion and major CIV drug cosign method, medication preparation procedure)	Standard protocol training related to medication administration	4.7 ± 0.6	0.94
		Education for frequent medication errors	Training on major error cases such as insulin, narcotics, smart pump calculation errors, regulator operation errors, and high-risk drug errors	4.9 ± 0.3	1.00
Person	Target education	Patient/guardian participation education (7Right)	Education on injection speed, effects, and side effects through patient/guardian participation when administering medication	4.8 ± 0.6	0.94
		Customized medication training according to experience	Training on frequent medication errors by experience	4.8 ± 0.6	0.94
Environment	Safe medication culture/ environment	Publish and posting the medication safety newsletter	Protocol improvement and sharing major error cases	4.9 ± 0.3	1.00
		Patient safety rounding establishment campaign	Established as a culture rather than a temporary activity through campaigns	4.6 ± 0.7	0.88
		Medication safety small rounding	Creating a safety culture through rounds of causes and improvement strategies for each case of a medication safety accident in the form of a quiz	4.8 ± 0.6	0.94
		Campaign focused on medication	Coordinate nurse PRN nurse*'s work and cooperate with related departments so that the nurse in charge can focus on medication administration.	4.8 ± 0.6	0.94
		Establishing a culture of patient/ guardian participation	Establishment of a safe medication culture through the participation of patients/ guardians in medication administration	4.9 ± 0.3	1.00
		Establishment of medication safety counseling	Establishing a culture of counseling for improvement rather than criticism in case of medication safety accidents	4.9 ± 0.3	1.00
Technology	Technology utilization	Establishment of a medication information platform	Organizing preparation and administration methods of major mixed drugs and strengthening computer accessibility	4.6 ± 0.7	0.88
		Improving medication safety issues	Separate storage and labeling of confusing narcotics and insulin pens	4.9 ± 0.3	1.00
		Support for medication-related emergency consultation desks	Establishment of a medication-related counseling desk in the evening and on weekends when the manager is absent	4.7 ± 0.5	1.00
Organization	Promoting medication safety at the organizational level	Monitoring the status of patient safe rounding	Monitor patient safety rounding performance during handover	4.7 ± 0.6	0.94
		Monitor regulator usage	Monitor compliance with regulator operating protocol	4.6 ± 0.7	0.88

*PRN nurses works on an as-needed basis, rather than having a fixed schedule. In this research, the role of a PRN nurse is primarily focused on managing admissions, discharges, testing, and transport care rather than directly caring for assigned patients.

CVI indicates content validity index.

TABLE 4. Final MAEP (Medication Administration Error Prevention) Program

Intervention domain	(Details) intervention	Target	Implementation subject	Human	Task	Technology	Environment	Organization	Intervention cycle
Protocol reorganization and education for frequent medication errors	Regulator operation protocol standardization and training	For all nurses	Medication safety team, Nurse educator	v	v	v		v	At the beginning of every month, training for new employees and transferees. Announcement of online training via VOD
	Standardization of cosign method for major high-risk drugs	For all nurses		v	v			v	
	Standardization of medication preparation procedures (labeling of drug mixing methods)	For all nurses		v	v			v	
	Standardization of PDA usage method	For all nurses		v	v	v		v	
Patient safety rounding	Patient safety rounding	For all nurses	Head nurse Prn nurse* Nurse in charge of each patient	v	v			v	Handover time for each shift
Drug administration information platform	Organizing and posting information about major drug mixed solvents	For all nurses	Nursing Information Committee, Nursing-Pharmacy Council	v				v	Updated every year
	Operation of the emergency medication consultation desk	For all nurses	Educational nurse	v			v	v	Evening time, weekends
	Organizing and posting information on major drugs (PO, IV, etc.) for each ward	For all nurses	Educational nurse	v					Updated every year
Customized medication training based on experience	Changes in medication training module for new nurses	For new nurses	Nurse educator	v	v	v	v	v	At the time of new nurse training
	Change in medication education module for transferred nurses	For nurses transferred in	Nurse educator	v	v	v	v	v	At the time of training for newly transferred nurses
	Change in education module related to frequent medication errors	For all nurses	Medication safety team, Nurse educator	v	v	v	v		In the early stage of intervention, quarterly
Reorganization of medication safety counseling	Change and standardization of medication safety counseling protocol: simulation, feedback	For all nurses	Medication safety team, Head nurse Nurse educator	v	v	v	v	v	In the early stage of intervention, quarterly
Fostering a culture focused on medication safety	Campaign to prevent interference when preparing medication: head nurse rounding, coordinating work between charge nurse and PRN nurse*	For the nurse in charge of each patient, For the patient's guardian	Head nurse PRN nurse*	v			v	v	In the early stage of intervention, quarterly

	Campaign to prevent interference when preparing medication: Meeting with related departments	Cooperation with related departments	Cooperation with other departments	v					v	
	Establishment of additional prescription preparation protocols: avoid hasty administration	Physician Nurse	Nursing and Medical department council	v						
Patient and guardian participation	Patient/guardian participation campaign when administering medication (7Right): infusion rate (regulator), insulin, adverse reactions	For all nurses For patient/guardian	Medication safety team	v	v	v				In the early stage of intervention, quarterly
Improving the environment that hinders medication safety	Improving confusing narcotics storage methods: classification of storage boxes and stickers by drug and capacity	For all nurses	Head nurse	v				v		In the early stage of intervention, quarterly
	Improving storage method for pen-type insulin: stickers, storage box	For all nurses	Nurse educator	v				v		
Promoting awareness of medication safety	Publish medication safety newsletter and post electronically: share for protocols and major error cases	For all nurses	Medication safety team, Nurse educator	v					v	At the beginning of every month
	Patient safety rounding best case contest	For all nurses		v					v	Quarterly
	Medication safety small rounding: newsletter distribution and quiz show	For all nurses		v					v	On the third week of every month

**Note*: PRN nurses work on an as-needed basis rather than having a fixed schedule. In the research ward, the role of a PRN nurse is primarily focused on managing admissions, discharges, testing, and transport care rather than directly caring for assigned patients.

TABLE 5. Homogeneity Test of the Variables of General Characteristics Between Intervention and Control Group

Variables	Categories	n (%)		P
		Intervention group (n = 36)	Control group (n = 37)	
Total work experience (y)	< 3 mo	2 (5.6)	2 (5.4)	0.78*
	≥ 3 mo and < 1 y	6 (16.7)	5 (13.5)	
	≥ 1 y and < 3	8 (22.2)	5 (13.5)	
	≥ 3 and < 5	3 (8.3)	6 (16.2)	
	≥ 5 and < 10	6 (16.7)	4 (10.8)	
	≥ 10 and < 15	5 (13.9)	9 (24.3)	
	≥ 15	6 (16.7)	6 (16.2)	
Current ward work experience (y)	< 3 mo	5 (13.9)	3 (8.1)	0.51*
	≥ 3 mo and < 1 y	9 (25.0)	6 (16.2)	
	≥ 1 y and < 3	14 (38.9)	14 (37.8)	
	≥ 3 and < 5	3 (8.3)	8 (21.6)	
	≥ 5	5 (13.9)	6 (16.2)	
Weekly work hours (h)	≥ 30 and < 40	17 (47.2)	21 (56.8)	0.56†
	≥ 40	19 (52.8)	16 (43.2)	
Direct patient interaction status	Yes	36 (100.0)	36 (97.3)	> 0.99*
	No	0 (0.0)	1 (2.7)	

*Note: Fisher Exact test.
†Pearson χ^2 test with Yates' continuity correction.

difference between the experimental group (3.35 ± 0.37) and the control group (3.46 ± 0.38) ($P = 0.211$). However, the experimental group had significantly lower preintervention scores for medication safety compliance (3.66 ± 0.39) compared with the control group (3.92 ± 0.42) ($P = 0.006$) (Table 6).

Results: DID analysis showed significant improvements in patient safety culture perception (0.42, $P < 0.001$) and medication safety compliance (0.53, $P < 0.001$), with large effect sizes ($d = 1.07$ and $d = 1.41$, respectively). The Cronbach alpha value for the patient safety culture awareness tool was 0.90, and for the medication safety compliance tool, it was 0.72 (Table 7).

Reported Medication Errors

Self-reported errors: the time series analysis model did not show statistical significance in error reporting rates between the experimental and control groups due to the short intervention period (Table 8).

Error reporting trends: in the experimental group, the error reporting rate increased from 5.0 to 13.2 per 100,000 administrations pre-intervention to 30.5 during the 37th month of intervention, then fluctuated between 11.0 and 20.2 reports. The control group maintained a low rate of around 4.17 reports (Fig. 3).

Comparative analysis: during the 3-month intervention period, the error rate in the experimental ward increased from 5.21 to 18.52 per 100,000 administrations, showing a slight increasing trend in no-harm error reports. In contrast, the error rate in the control ward decreased from 2.42 to 1.04 (Table 9). However, these findings were not statistically significant.

Overall, the program developed through the SEIPS model effectively addressed systemic issues in medication administration, demonstrating improvements in patient safety culture awareness and medication safety compliance among nurses.

DISCUSSION

Development of a SEIPS Model-based Medication Administration Error Prevention Program

This study developed an intervention program based on the SEIPS model, considering interactions among humans, tasks, technology(tools), environment, and organization. The program was refined through a literature review and expert panel discussions using the Delphi method, resulting in detailed intervention content, targets, implementers, and cycles. Our expert panel emphasized the need for specific protocols and tools, such as regulators for high-risk injectables and adherence monitoring.

The study by Maaskant et al[30] demonstrated that double-checking and barcode PDA (Personal Digital Assistant) systems can help reduce medication administration errors and enhance patient verification. However, a lack of standardized methods for nurses (humans) can nonetheless lead to errors. Our study standardized protocols for double-checking, labeling, mixing medications (task), and PDA usage (technology) and posted these standardized procedures online for the wards (organization). By intervening in the interactions between the 5 elements of the SEIPS

TABLE 6. Preintervention Dependent Variables of the Intervention and Control Groups

Dependent variables	M ± SD			t	P
	Intervention group (n = 36)	Control group (n = 37)	Total (n = 73)		
Patient safety culture (score)	3.35 ± 0.37	3.46 ± 0.38	3.40 ± 0.37	1.26	0.211
Medication safety compliance (score)	3.66 ± 0.39	3.92 ± 0.42	3.79 ± 0.42	2.84	0.006

TABLE 7. Results of Difference-in-Differences Analysis on the Intervention Effect

Outcome	Group	$M \pm SD$			Difference-in-difference	
		Preintervention	Postintervention	Difference for prepost	β_4	*P*
Patient safety culture (score)						
Total	Intervention (n = 36)	3.35 ± 0.37	3.69 ± 0.26	0.35	0.42	< 0.001
	Control (n = 37)	3.46 ± 0.38	3.38 ± 0.28	−0.08		
Teamwork	Intervention (n = 36)	3.86 ± 0.42	3.99 ± 0.38	0.13	0.17	0.213
	Control (n = 37)	3.90 ± 0.44	3.86 ± 0.36	−0.04		
Staffing workplace	Intervention (n = 36)	3.22 ± 0.47	3.12 ± 0.55	−0.10	−0.13	0.496
	Control (n = 37)	3.13 ± 0.69	3.16 ± 0.59	0.03		
Organizational learning	Intervention (n = 36)	3.34 ± 0.44	4.28 ± 0.54	0.94	0.99	< 0.001
	Control (n = 37)	3.47 ± 0.41	3.41 ± 0.40	−0.05		
Response to error	Intervention (n = 36)	3.30 ± 0.66	3.76 ± 0.59	0.46	0.40	0.044
	Control (n = 37)	3.46 ± 0.61	3.52 ± 0.49	0.06		
Leader support	Intervention (n = 36)	3.69 ± 0.61	4.11 ± 0.46	0.42	0.49	0.012
	Control (n = 37)	3.89 ± 0.62	3.82 ± 0.61	−0.07		
Communication about error	Intervention (n = 36)	3.73 ± 0.58	3.94 ± 0.70	0.20	0.36	0.088
	Control (n = 37)	3.86 ± 0.56	3.71 ± 0.65	−0.15		
Communication openness	Intervention (n = 36)	3.16 ± 0.55	3.28 ± 0.37	0.12	0.67	< 0.001
	Control (n = 37)	3.56 ± 0.51	3.01 ± 0.48	−0.55		
Reporting patient safety events	Intervention (n = 36)	3.17 ± 1.04	3.64 ± 0.62	0.47	0.55	0.037
	Control (n = 37)	3.50 ± 0.77	3.48 ± 0.68	−0.08		
Hospital management support	Intervention (n = 36)	3.20 ± 0.39	3.26 ± 0.44	0.06	0.10	0.552
	Control (n = 37)	3.14 ± 0.55	3.10 ± 0.62	−0.05		
Handoffs and information exchange	Intervention (n = 36)	3.46 ± 0.51	3.69 ± 0.46	0.22	0.18	0.350
	Control (n = 37)	3.40 ± 0.67	3.44 ± 0.61	0.05		
Patient safety rating	Intervention (n = 36)	2.69 ± 0.58	3.58 ± 0.77	0.89	0.86	< 0.001
	Control (n = 37)	2.73 ± 0.65	2.76 ± 0.49	0.03		
Medication safety compliance (score)						
Total	Intervention (n = 36)	3.66 ± 0.39	4.19 ± 0.36	0.54	0.53	< 0.001
	Control (n = 37)	3.92 ± 0.42	3.93 ± 0.31	0.01		
Ignore guidelines for quick work (rev)	Intervention (n = 36)	3.92 ± 0.60	4.36 ± 0.54	0.44	0.80	< 0.001
	Control (n = 37)	4.11 ± 0.66	3.76 ± 0.76	−0.35		
Always follow guideline	Intervention (n = 36)	3.47 ± 0.91	3.86 ± 0.99	0.39	0.39	0.165
	Control (n = 37)	3.89 ± 0.70	3.89 ± 0.74	0.00		
Perform work considering the possibility of an accident	Intervention (n = 36)	3.56 ± 0.73	4.11 ± 0.82	0.56	0.45	0.114
	Control (n = 37)	3.73 ± 0.99	3.84 ± 0.83	0.11		
Wear protective gear when administering	Intervention (n = 36)	3.83 ± 0.88	4.14 ± 0.90	0.31	0.09	0.728
	Control (n = 37)	4.03 ± 0.73	4.24 ± 0.55	0.22		
Maintain a clean environment when administering	Intervention (n = 36)	3.89 ± 0.62	4.39 ± 0.96	0.50	0.47	0.050
	Control (n = 37)	4.08 ± 0.68	4.11 ± 0.57	0.03		
Encourage colleagues to take medication safety	Intervention (n = 36)	3.22 ± 0.80	4.33 ± 0.83	1.11	0.68	0.016
	Control (n = 37)	3.51 ± 1.02	3.95 ± 0.66	0.43		
Prepare protective equipment for a safe environment	Intervention (n = 36)	3.64 ± 0.90	4.31 ± 0.75	0.67	0.75	0.005
	Control (n = 37)	3.95 ± 0.66	3.86 ± 0.86	−0.08		
Follow only some guidelines for quick work(rev)	Intervention (n = 36)	3.64 ± 0.83	4.33 ± 0.48	0.69	0.78	0.004
	Control (n = 37)	3.84 ± 0.90	3.76 ± 0.89	−0.08		

TABLE 7. (continued)

Outcome	Group	$M \pm SD$ Preintervention	$M \pm SD$ Postintervention	Difference for prepost	Difference-in-difference β_4	Difference-in-difference P
Do not follow guidelines if you think they are unnecessary(rev)	Intervention (n = 36)	3.89 ± 0.78	4.28 ± 0.57	0.39	0.20	0.442
	Control (n = 37)	3.92 ± 0.95	4.11 ± 0.77	0.19		
Report any accidents or possible accidents to the head nurse	Intervention (n = 36)	3.72 ± 0.70	4.03 ± 0.45	0.31	0.39	0.075
	Control (n = 37)	4.24 ± 0.68	4.16 ± 0.73	−0.08		
Proactively correct to prevent accidents	Intervention (n = 36)	3.44 ± 0.69	3.97 ± 0.51	0.53	0.80	< 0.001
	Control (n = 37)	3.86 ± 0.63	3.59 ± 0.50	−0.27		

regression model $Y = \beta_1 + \beta_2 D_1 + \beta_3 D_2 + \beta_4(D_1 \times D_2)$; SD.

model, we maximized the error prevention effect, which is a distinguishing feature of our study.

We incorporated systematic monitoring to detect and correct errors early, developed an online drug information platform, and established emergency consultation desks during off-hours. Recognizing the limitations of traditional medication safety education highlighted in the studies by Conroy et al[24] and Acheampong et al,[26] we developed educational modules based on nurses' experiences and incorporated simulations and feedback to address frequent errors. To address distractions during medication preparation,[8] as highlighted in the study by Lapkin and colleagues, we redefined the roles of primary and PRN nurses to manage emergent needs and phone calls, promoting a medication-focused culture.

Our multifaceted intervention program, which included protocol standardization, education, rounding, information platforms, and environmental adjustments, aligned with SEIPS model principles to improve nurse compliance and error reporting. This approach shifts the focus from attributing errors solely to individual nurse performance to addressing systemic issues, validating the program's effectiveness and the importance of theoretically grounded interventions in clinical settings.

Evaluation of the Program Validity

Patient Safety Culture Awareness and Medication Safety Compliance

The intervention program significantly increased patient safety culture awareness by ~0.42 points ($P < 0.001$) and medication safety compliance by ~0.53 points ($P < 0.001$). Improvements in continuous organizational learning, response to errors, leadership support, open communication, and reporting patient safety incidents were notable. These findings align with Thu et al,[37] who emphasized the importance of open communication and continuous organizational learning in improving patient safety culture and compliance.

Communication about errors should include positive feedback and interactions between departments and the QA department to improve patient safety culture and address poor practices, as demonstrated in the study by Hameed et al.[38] While our program significantly improved communication openness, communication about errors showed only partial improvement, indicating the need for additional interventions to enhance interdepartmental communication.

Staffing and Work Environment

Improvements in staffing, such as better nurse-to-patient ratios and increased administrative support, positively impacted nursing performance and patient safety in the study by Ji and Lee.[39] Our program did not address staffing improvements, resulting in no significant improvement in areas related to hospital management support and staffing. Future research should consider the impact of increased nursing hours through staff additions on patient safety improvements.

Medication Safety Compliance

Medication safety compliance also showed significant improvement, indicating meaningful enhancement not only in awareness of patient safety but also in the implementation of safety behaviors related to medication. This improvement was observed in specific areas of compliance, such as

TABLE 8. Results of Interrupted Time Series Analysis With Nonequivalent Control Group Design on Medication Error Reporting Rate

Variables	Coefficient	SE	*t*	*P*
Intercept (β_1)	2.09	1.05	2.00	0.049
Time (β_2)	−0.29	0.44	−0.67	0.507
Group (β_3)	3.59	1.77	2.03	0.046
Intervention (β_4)	−0.08	0.10	−0.83	0.410
Trend (β_5)	1.00	1.75	0.58	0.567
Time×trend (β_6)	−0.76	0.36	−2.12	0.037
Group×trend (β_7)	18.49	5.90	3.14	0.002
Intervention×trend (β_8)	−1.01	1.70	−0.59	0.555

adherence to principles during medication administration, encouragement of safety compliance among team members, provision of protective gear to maintain a safe medication environment, and consideration of potential medication-related issues during administration. However, reporting medication safety incidents or potential incidents to superiors, although improved after the intervention, did not show significant improvement, suggesting the need for more prolonged interventions. This result is similar to the findings of Xu et al[9] where there was significant improvement in adherence to procedures after interventions on 5 aspects, although their study involved direct observation of some subjects, whereas this study used self-reports from all participating nurses. Anugrahini and Hariyati's[40] literature review on nurses' medication safety compliance to reduce medication administration errors suggests that, instead of attributing noncompliance with medication principles or guidelines to individual nurses' lack of knowledge or behavior, it is essential to evaluate the overall environment and technical support systems (such as smart pumps and computerized decision support systems) in which medication administration occurs. Improving these environmental and technical elements can enhance nurses' medication safety compliance, particularly by improving error reporting.

Self-Reported Medication Errors

Anugrahini and Hariyati demonstrated that addressing environmental and technological factors can improve compliance and error reporting.[40] According to Jang et al,[41] most errors (77.3%) were reported by nurses with less than 3 years of experience, and these nurses reported more errors when they had higher patient safety culture awareness. This study suggests that the increasing trend in error reporting in the intervention group could be attributed to the rise in safety culture awareness among less experienced nurses. However, to statistically and clearly establish these findings, further research with sufficient data and a longer study duration is necessary.

Reporting of Errors Without Harm

The expert panel discussions revealed that major medication errors were primarily caused by inappropriate dosages, speeds, and incorrect medications, findings consistent with Koo's study.[6] The increase in reporting errors without harm postintervention indicates a cultural shift toward easier reporting of incidents, regardless of whether harm occurred. This is consistent with Kim and Kim's findings,[36] which emphasize the importance of leadership in fostering error reporting and the need to promote reporting intentions without fear of blame.

In summary, the SEIPS model-based intervention program effectively improved nurses' awareness of patient safety culture and medication safety compliance. The increase in medication error reporting rates and the rise in reporting nonharm incidents after the intervention suggest that the program could significantly enhance patient safety if applied for a longer duration. The improvements in patient safety culture and medication safety compliance are consistent with the findings of Basson et al[42] and Alomari et al.[43] However, regarding medication error reporting rates, Basson and colleagues' study did not show an increase in error reporting rates, and Alomari and colleagues' study indicated a decrease in the reporting of safety incidents, suggesting that caution is needed when interpreting these results.

This study applied the program to a single adult general ward in a general hospital, which limits its generalizability. Therefore, additional research is needed to apply it to various settings, such as pediatric wards, intensive care units, and emergency rooms, as well as across multiple institutions, to generalize its validity. In addition, the short application period of 3 months posed limitations in

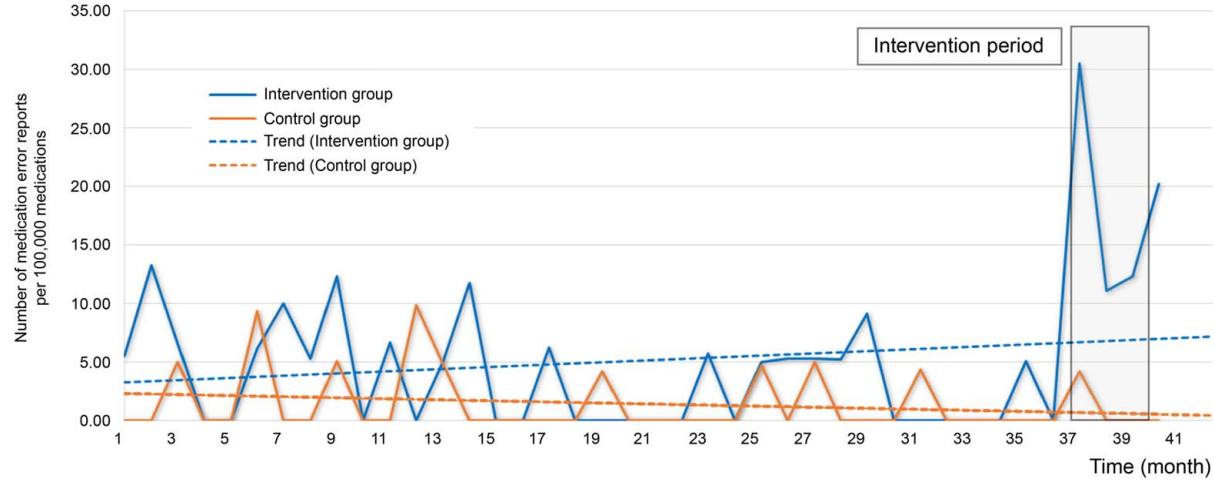

FIGURE 3. Results of interrupted time series analysis with nonequivalent control group design on medication error reporting rate.

TABLE 9. Comparison of Reported Medication Errors During the Same Period Before and After Intervention

	Intervention group		Control group	
	Before	After	Before	After
Medication error/total medication (n)	4/76,755	12/64,794	2/82,644	1/96,153
Medication error rate (n/100,000)	5.21	18.52	2.42	1.04
Patient outcome after medication error (n)				
No harm	1	11		
Mild harm	2	1	1	
Moderate harm	1		1	1
Type of medication error (n)				
Overdose	2	3	1	
Wrong rate	1	3	1	1
Wrong drug		2		
Wrong patient	1	1		
Wrong time		1		
Dose omission		1		
Other		1		

confirming a 'significant increase in medication administration error reporting rates. This study relied on self-reports for data collection on medication safety compliance and medication administration errors instead of direct observation, so potential self-report bias should be considered when interpreting the results. Therefore, evaluating the program's validity through long-term application in various settings and institutions is necessary. Directly observing medication safety compliance and medication administration errors can help confirm the program's effectiveness.

CONCLUSION

This study confirms the validity of a theoretically grounded multifaceted intervention program to prevent medication administration errors among nurses. By shifting the focus from solely attributing medication safety issues to nurse education and individual capabilities, the program underscores the importance of systemic factors. This comprehensive approach provides a foundational basis for developing medication safety education programs and shaping patient safety policies.

This approach not only enhances patient safety culture awareness and medication safety compliance but also promotes a broader systemic understanding and handling of medication errors in clinical settings.

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