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Original Article

The Effect of Computerized Decision Support System in Preventing of High-risk Medication Errors in Pediatric Patients

Pediyatrik Hastalarda Yüksek Riskli İlaç Hatalarının Önlenmesinde Bilgisayarlı Karar Destek Sisteminin Etkisi

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ABSTRACT

Objective: This study aimed to examine the effect of a web-based double check program, developed as a computerised decision support system, on preventing high-risk medication errors among pediatric nurses.

Method: This quasi-experimental study was conducted using a single-group pretest-posttest design in the pediatric surgery clinics of a university hospital. The sample consisted of all high-risk medication administrations performed by 24 nurses. Medication error rates were determined through direct observation before the intervention. Subsequently, nurses administered medications using the web-based double check program, and medication error rates were reassessed after the interventions. Data were analysed using IBM Statistical Package for the Social Sciences software program. Ethical approval, institutional permission, and informed consent were obtained.

Results: The average rates of medication error were 47.8% before and 19.4% after the interventions, indicating a substantial reduction in medication error rates following implementation of the web-based double check program. The overall medication error rate was calculated as the arithmetic mean of stage-specific (preparation, administration, patient monitoring, and documentation).

Conclusion: The use of the web-based double check program significantly reduced medication error rates among pediatric nurses. Integration of computerized decision support systems into clinical practice may contribute to improved medication safety in pediatric settings.

Keywords: Child, pediatric nursing, medication errors, decision support systems, clinical patient safety

ÖZ

Amaç: Bu çalışma, bilgisayarlı bir karar destek sistemi olarak geliştirilen web tabanlı bir çift kontrol programının, pediyatri hemşireleri arasında yüksek riskli ilaç hatalarının önlenmesine etkisini incelemek amacıyla yapılmıştır.

Yöntem: Bu yarı deneysel çalışma, bir üniversite hastanesinin pediyatrik cerrahi kliniklerinde tek grup ön-son test tasarımı kullanılarak gerçekleştirilmiştir. Örneklem, 24 hemşire tarafından gerçekleştirilen tüm yüksek riskli ilaç uygulamalarından oluşmuştur. Müdahale öncesinde ilaç hatası oranları doğrudan gözlem yoluyla belirlenmiştir. Ardından, hemşireler web tabanlı çift kontrol programını kullanarak ilaçları uygulamışlar ve müdahalenin ardından ilaç hatası oranları yeniden değerlendirilmiştir. Veriler SPSS yazılımı kullanılarak analiz edilmiştir. Etik kurul onayı, kurum izni ve bilgilendirilmiş onam alınmıştır.

Bulgular: Müdahale öncesinde ortalama ilaç hatası oranı %47,8 iken, müdahale sonrasında bu oran %19,4'e düşmüştür; bu durum, web tabanlı çift kontrol programının uygulanmasının ardından hatalarda önemli bir azalma olduğunu göstermektedir. Genel ilaç hatası oranı, aşamalara özgü hata oranlarının (hazırlama, uygulama, izleme ve belgeleme) aritmetik ortalaması olarak hesaplanmıştır.

Sonuç: Web tabanlı çift kontrol programının kullanımı, çocuk hemşireleri arasında ilaç hatası oranlarını önemli ölçüde azaltmıştır. Bilgisayarlı karar destek sistemlerinin klinik uygulamaya entegrasyonu, çocuk sağlığı hizmetlerinde ilaç güvenliğinin iyileştirilmesine katkıda bulunabilir.

Anahtar kelimeler: Çocuk, pediyatri hemşireliği, ilaç hataları, karar destek sistemleri, klinik hasta güvenliği

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INTRODUCTION

Medication administration is one of the fundamental legal responsibilities of nurses and plays a critical role in patient safety. Medication errors are defined as preventable malpractices that may lead to inappropriate medication use or patient harm during prescribing, preparation, or administration processes of medications[1,2]. These malpractices remain among the most common adverse events reported in healthcare settings[3].

Medication errors occur more frequently during administration of medications to pediatric patients compared to adults due to physiological differences between adult and pediatric patients including, weight-based dosing requirements, and the need for individualized drug calculations[4-9]. In particular, children aged 0-4 years are reported to be at higher risk for medication administration-related malpractices[10]. Common medication errors in pediatric clinical practice include incorrect dose calculation, improper dilution of medications, incorrect infusion rate, and failure to verify safe dose ranges. Such errors may arise from heavy workload, insufficient staffing, interruptions during medication preparation, lack of standardized protocols, and inadequate double-check practices[5,11-13].

Nurses play a central role in preventing medication errors, especially during the preparation and administration stages of medications. Although physicians prescribe medications, nurses are responsible for verifying correct dose ranges, preparing medications in accordance with hygienic regulations, and ensuring adherence to medication administration principles. Therefore, the implementation of effective strategies that nurses must follow in medication processes is essential for improving patient safety[14-16].

International organizations such as the World Health Organization recommend the use of standardized medication protocols and double-checked procedures, particularly for administration of high-risk medications[17]. However, in many clinical settings, especially where staffing shortages exist, manual double-checks by another healthcare professional may not always be feasible. This limitation highlights the need for alternative technological solutions that support safe administration of medications[15,18-24].

Computerized decision support systems have emerged as promising tools for reducing medication errors by providing automated dose calculations, drug information, and standardized administration protocols. Despite the growing interest in technological interventions, still limited number of studies have evaluated the effectiveness of web-based double-check systems in administration of high-risk medications to pediatric patients[18-23].

Therefore, this study aimed to examine the effect of a web-based double check program developed as a computerized decision support system on preventing high-risk medication errors made by pediatric nurses.

Research Question: Is the "web-based double check program" effective in reducing error rates during the administration of high-risk medications to pediatric patients?

MATERIALS and METHODS

Study Design and Setting

This quasi-experimental study was conducted using a single-group pretest-posttest study design to evaluate the effectiveness of the web-based double check program in improving the safety of high-risk medication administration among pediatric patients. Data were collected using a non-participant observation method, which is considered as an objective approach for detecting medication administration errors.

This study was carried out between November 2017 and June 2018 in the pediatric surgery clinic, pediatric surgery intensive care unit, and neonatal surgery intensive care unit of a university hospital in Türkiye where patients aged 0-18 years were hospitalized.

Study Population and Sample Size

The population of the study consisted of nurses working in the pediatric surgery-related units of the study hospital and administration of the high-risk medications by these nurses was assessed.

In this study, the pediatric population included patients receiving high-risk medications, which were defined as drugs associated with an increased risk of significant harm when administered erroneously. These medications consisted of intravenous antibiotics (such as vancomycin and meropenem), insulin, anticoagulants (e.g., heparin), concentrated electrolytes (e.g., potassium chloride), sedatives, and opioid analgesics, which are widely recognized as high-risk medications also used in pediatric care[1-3].

Eligibility criteria for participation of nurses were as follows:

- administering medications categorized as high-risk drugs for pediatric patients,
- voluntary participation in the study,
- having adequate internet usage skills to use the web-based program.

During the study period, 31 nurses were working in the relevant clinics. Nurses who were not actively involved in medication administration (charge nurse, chief nurse, polyclinic nurse, and training nurse), nurses who were not in duty during the study period, and those who declined participation were excluded. Consequently, 24 nurses were included in the study sample.

All nurses included in the study held a bachelor's degree; two (8.3%) had a master's degree, five (20.8%) were continuing their master's degree program, and one (4.2%) was pursuing her doctoral education. All participants were female, with a mean age of 33.08±6.47 years. The mean duration of pediatric nursing experience was 8.00±5.52 years. No new nurses joined or left the clinics during the study period, ensuring consistency between pre-and post-intervention observations.

Determination of the Sample Size

The research sample consisted of high-risk medications administered by nurses during the observation periods. The sample size was calculated using G*Power (version 3.1.9.4) based on a comparison of two independent proportions (chi-square test). An effect size of 0.3 (medium effect, according to Cohen's conventions), a type I error (α) of 0.05, and a statistical power of 0.95 (1-β) were assumed. The minimum required sample size was determined to be 530 observations. Achievement of a higher statistical power was preferred to increase the sensitivity of detecting clinically significant differences in medication error rates. During the study, 532 administrations of medications were observed before and 538 after the intervention, yielding a total of 1070 medication observations, which exceeded the required sample size. To evaluate the adequacy of sample size and the statistical power of the findings, a post- hoc power analysis was conducted using G*Power 3.1.9.4. Based on the observed effect size (Cohen's w=0.301) calculated from the primary outcome variable (overall medication error rate), and comparing the pre- and post-intervention groups, the statistical power of the study (1-β) was estimated as 1.000. This result indicates that the sample size was sufficient to detect significant differences between groups.

Data Collection

Observation Process

Relevant data were collected using a non-participant observation method to identify medication administration errors. This observation technique was selected because it provides more objective and reliable results compared to incident report analysis or retrospective record review methods. Schnock et al.[6] reported that the use of observation method in determining medication errors would provide objective results and it is a more reliable and effective method compared to the methods of examining erroneous and clinical records.

At the beginning of the observation phase, two observers independently conducted the first 30 medication observations in order to assess the medication observation form. The second observer was a nurse with clinical experience and postgraduate education in pediatric nursing.

Inter-observer agreement was evaluated using Kappa Power Analysis, and the agreement level was found to be 0.95, indicating excellent reliability[25]. After confirming inter-observer consistency, all subsequent observations were conducted by the principal researcher.

Medication administration errors were first recorded before the implementation of the web-based double check program conducted in three separate sessions by the researcher. Following baseline observations, user accounts were created for all participating nurses, and the program was installed on their mobile devices.

Training sessions on the use of the web-based double check program were conducted in three separate sessions by the researcher. After completing the training, a preliminary trial phase was initiated to ensure that all nurses were familiar with the system and able to use it effectively.

Following this preparation phase, the web-based double check program was integrated into routine medication practices in the clinic. During this intervention period, stages of the medication administration processes were again observed, and medication error rates were recorded using the same observational method.

The overall observation process, including the pre-intervention, training, pilot testing, and post-intervention phases, is presented as a flow diagram in Figure 1 to enhance clarity and transparency of the study design.

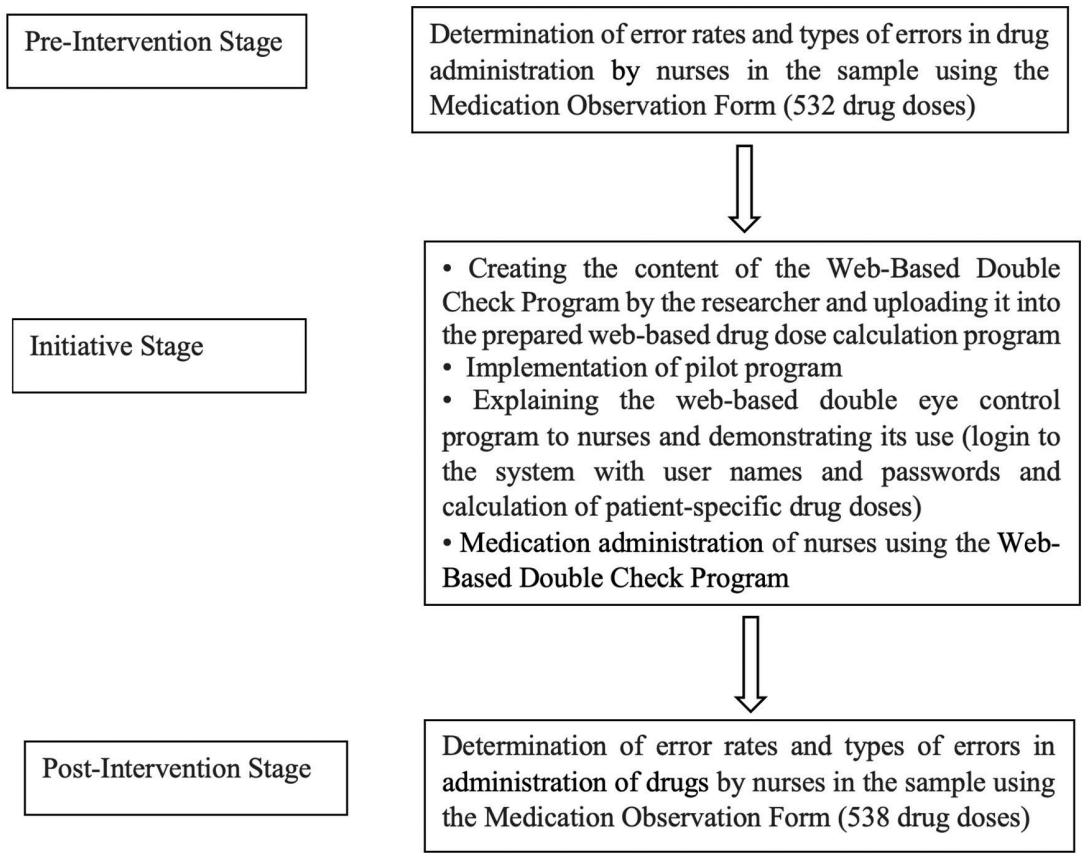

Figure 1. Research flow diagram

Medication Observation Form

Medication administration errors were identified using the medication observation form, which was developed by the researchers based on the relevant literature data[26,27].

This form was designed to evaluate all stages of the medication process including:

- preparation of medications,
- administration of medications,
- patient monitoring,
- documentation and recording.

To ensure content and scope validity, expert opinions were obtained during the development of the form. Based on expert feedback, necessary revisions were made before initiation of the data collection phase.

Medication errors recorded using this form were evaluated according to:

- hospital medication protocols,
- the 10 rights of medical administration (correct medicine, correct dose, correct patient, correct time, correct route of medication, correct medicine form, correct medicine management, correct record, correct response and correct information),
- deviations from standardized medication skill steps defined in the web-based double check program,
- relevant literature-based medication safety standards[26,27].

Web-based Double Check Program

The web-based double check program was developed using a structured multi-stage process.

In the first stage, a web-based platform (www.decpro.net) was created. In the second stage, medication preparation, administration, and follow-up guidelines for the administration of high-risk medications were developed based on a comprehensive literature review[28-30].

In the third stage, expert evaluation was consulted to ensure content validity. Drug-related content included in the program was reviewed by a panel of five experts from pharmacology and pharmacy disciplines. Content validity was assessed using Fleiss' Kappa statistical analysis, and an agreement level of 0.86, indicating excellent agreement, was obtained.

After content validation, the program was pilot-tested for 15 days by 10 pediatric nurses working in pediatric clinics at two different university hospitals outside the study setting.

Feedback obtained from the pilot users was analyzed using thematic analysis, and the results indicated that the program was:

- easy to use,
- provided a practical method for entering patient data,
- helpful in preventing medication errors.

Following the pilot phase, training sessions were conducted for nurses in the clinics where the study was conducted. Each nurse received a username and password, and the system was activated for clinical use.

The program allows nurses to enter patient-specific data, including ages, body weights of the patients, and doses of the prescribed medications. Based on these inputs, the program automatically calculates the appropriate dose for the patient and verifies whether the prescribed dose falls within the safe dose range. In addition, standardized drug administration guidelines are accessible through the program interface.

During the post-intervention phase, this system was used in all observed medication administrations.

Statistical Analysis

Statistical analyses were performed using SPSS software (IBM SPSS Statistics, version 22.0), and a p-value of <0.05 was considered statistically significant.

Descriptive statistics were used to summarize medication error frequencies and percentages observed during the pre-and post-intervention periods. Differences between pre- and post-intervention error rates were analyzed using the chi-square (χ^2) test of independence.

To reduce the increased risk of type I errors associated with multiple hypothesis testing, Holm-Bonferroni correction was applied to all p-values obtained from comparisons of individual medication error types.

The overall medication error rate was calculated as the arithmetic mean of error rates across different stages of the medication administration process (preparation, administration, patient monitoring, and documentation). Although these categories represent heterogeneous components of the medication process, arithmetic averaging was used to provide a composite and interpretable indicator reflecting the general level of medication safety performance. This approach has been used in previous observational medication safety studies to summarize multidimensional error structures and express them as a single outcome measure[31]. However, it is acknowledged that this method assumes equal weighting of error categories and may not fully capture the clinical significance of individual error types.

To ensure consistency in terminology, the term "medication error rate" was used throughout the manuscript to refer to the proportion of observed medication administrations with at least one error. The term "overall medication error rate" specifically refers to the composite indicator calculated from stage-specific error rates. Each stage was given equal weight in the calculation of the overall medication error rate, as no predefined weighting criteria were available for different error types. This approach was selected to provide a simple and interpretable summary measure of overall medication safety performance.

For consistency, the term "dose verification" was used to refer to the process of checking whether the prescribed dose falls within the safe dose range.

This study was derived from the author's doctoral thesis completed in 2018. In the present manuscript, results of the statistical analyses were re-evaluated and updated in accordance with reviewers' recommendations. Specifically, the application of chi-square (χ^2) test of independence and Holm-Bonferroni correction provided a more rigorous control of type I error. In addition, 95% confidence intervals (CIs) were calculated for all observed medication error rates to improve the interpretability and clinical relevance of the findings. Consequently, some p-values differ from those reported in the original thesis.

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ege University Faculty of Medicine Clinical Research Ethics Committee (decision no: 17-11/37, dated: 14.11.2017), and institutional permission was obtained from the hospital where the study was conducted

(decision no: 299596, dated: 21.11.2017). Written informed consent was obtained from all participating nurses. The study was retrospectively registered at ClinicalTrials.gov (NCT06371690; 15.04.2024).

RESULTS

In this quasi-experimental study conducted to reduce the rates of medication administration errors made by nurses, a total of 1070 medication administrations were observed before and after the implementation of the double check program.

Table 1 presents medication error rates according to the stages of the medication administration process. The medication preparation error rate decreased from 92.9% before the intervention to 33.6% after the intervention (χ^2=7.936, p=0.004). The rate of not performing safe dose verification significantly decreased from 92.9% to 17.3% (χ^2=8.557, p=0.003). The rate of not performing medication route verification significantly decreased from 39.3% to 13.2% (χ^2=3.879, p=0.049), and the rate of not evaluating vital signs before and/or after medication decreased from 12.4% to 9.6% (χ^2=7.989, p=0.005). Similarly, the rates of monitoring errors decreased from 61.5% to 22.3%

Table 1. Distribution of medication error rates before and after implementation of the web-based double check program with 95% confidence intervals and Holm-Bonferroni adjustment (n=1070)

Error types	Pre-intervention		Post-intervention		χ^2	p
	n	(95% CI)	n	(95% CI)		
Medication preparation error	494	92.9 (90.7-95.1)	181	33.6 (29.6-37.6)	7.936	**0.004***
Failure to adhere to drug preparation time points	365	68.6 (64.6-72.5)	181	33.6 (29.6-37.6)	0.567	0.452
Failure to use aseptic techniques during preparation of medications	41	7.7 (5.5-10.2)	13	2.4 (1.3-4.1)	1.113	0.291
Dosing error	108	20.3 (17.0-23.9)	58	10.9 (8.4-13.8)	0.180	0.672
Failure to verify safe doses	494	92.9 (90.7-95.1)	92	17.3 (14.2-20.8)	8.557	**0.003***
Drug dilution error	206	38.7 (34.6-42.9)	43	8.1 (6.0-10.8)	3.052	0.081
Using pre-prepared medication	23	4.3 (2.7-6.4)	11	2.1 (1.0-3.7)	0.508	0.476
Failure to label the medication	64	12.0 (9.4-15.1)	20	3.8 (2.3-5.7)	2.842	0.092
Rate of medication error	398	74.8 (71.0-78.4)	239	44.4 (40.2-48.7)	2.466	0.132
Failure to adhere to medication administration times	201	37.8 (33.7-42.0)	138	25.9 (22.3-29.8)	1.430	0.232
Failure to check medication administration route	209	39.3 (35.2-43.5)	70	13.2 (10.5-16.3)	3.879	0.049
Failure to evaluate drug adherence	203	38.2 (34.1-42.4)	31	5.8 (4.0-8.2)	0.486	0.486
Not evaluating vital signs (pre/post)	66	12.4 (9.8-15.5)	51	9.6 (7.2-12.3)	7.989	**0.005***
Failure to use aseptic techniques during administration of medications	22	4.1 (2.6-6.2)	9	1.7 (0.8-3.2)	1.124	0.289
Failure to specify drug infusion rate	225	42.3 (38.1-46.6)	52	9.8 (7.4-12.6)	0.352	0.553
Dose skipping error	28	5.3 (3.5-7.5)	31	5.8 (4.0-8.2)	0.12	0.73
Wrong patient	0	0 (0-0.7)	0	0 (0-0.7)	-	-
Wrong medicine	0	0 (0-0.7)	0	0 (0-0.7)	-	-
Rate of monitoring error	327	61.5 (57.2-65.6)	120	22.3 (18.9-25.9)	3.879	0.030
Rate of recording error	367	69.0 (65.0-72.8)	181	33.6 (29.6-37.6)	0.385	0.554
Overall error rate	523	98.3 (96.7-99.2)	308	57.2 (53.0-61.3)	3.767	0.049

A single medication administration may include more than one error type

*: Holm-Bonferroni correction was applied to adjust for multiple comparisons. After correction, statistically significant differences remained only for preparation errors, failure both to perform safe dose verification, and to evaluate vital signs before and/or after medication administration

Values are presented as numbers (n), percentages (%) and 95% confidence intervals. Confidence intervals were calculated using binomial distribution assumptions

CI: Confidence interval, χ^2: Chi-square test, p: Level of statistical significance

(χ^2=3.879, p=0.030). The overall medication error rate showed a statistically significant reduction, decreasing from 98.3% before the intervention to 57.2% after the intervention (χ^2=3.767, p=0.049).

However, after applying Holm-Bonferroni correction for multiple comparisons, statistically significant reductions remained only in: preparation errors (p=0.004), failure to perform safe dose verification (p=0.003), and failure to evaluate vital signs before and/or after medication administration (p=0.005).

Although reductions were also observed in medication route verification, medication monitoring, and overall medication error rates, these differences did not remain statistically significant after adjustment for multiple comparisons.

Other medication error types, including medication preparation time, drug dilution, infusion rate, and documentation-related errors reduced-though not statistically significantly-following implementation of the web-based double check program.

The overall medication error rate, calculated as the arithmetic mean of error percentages observed across all medication administration stages, including preparation, administration, recording and patient monitoring, is presented in Figure 2. The overall medication error rate, calculated as the arithmetic mean of stage-specific error rates was 47.8% among 532 medication administrations observed before the intervention and 19.4% among 538 medication administrations observed after the intervention, indicating an overall improvement in medication safety performance.

DISCUSSION

In this study, the effectiveness of a web-based double check program in reducing medication errors during administrations of high-risk drug to pediatric patients was evaluated. The findings demonstrated that the implementation of the program resulted in a substantial reduction in medication error rates across stages of the medication administration process.

This composite measure should be interpreted as a summary indicator of overall medication safety performance rather than a direct measure of individual error severity. The observed reduction supports the effectiveness of structured and technology-assisted double-checking strategies in improving medication safety[18-23]. Similar findings have been reported in previous studies demonstrating that structured interventions and decision-support systems significantly reduce medication errors in clinical settings[6,8,18-23,32]. These findings collectively support the role of digital solutions

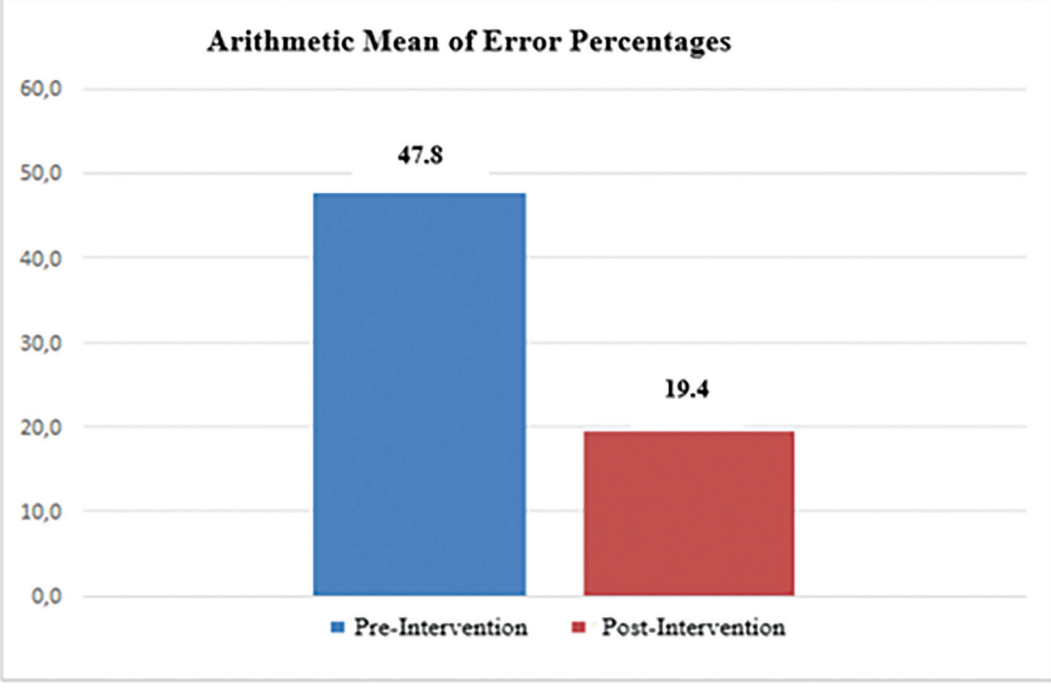

Figure 2. Overall medication error rates calculated as the arithmetic mean of stage-specific error percentages before and after the intervention

in minimizing human-related errors during complex medication processes. A notable strength of this study is that the web-based double check program was available and incorporated into routine medication administration procedures during the post-intervention phase. The system was observed to be used during medication administrations included in the post-intervention period. However, adherence was not systematically quantified using predefined compliance measures. Therefore, the observed reduction in medication errors should be interpreted with this limitation in mind.

After adjustment for multiple comparisons using the Holm-Bonferroni correction, statistically significant reductions were achieved in the rates of preparation errors, failure to perform safe dose verification, and to evaluate vital signs before and/or after administration of medications. These findings indicate that the intervention was particularly effective in improving medication safety practices related to medication preparation accuracy, dose calculation, and patient monitoring procedures. Among individual error types, failure to perform safe dose verification was identified as one of the most frequent errors made before implementation of the intervention, and a statistically significant reduction was obtained after statistical correction. This finding highlights the importance of structured dose calculation and verification systems in preventing dosage-related errors, particularly in pediatric settings where medication doses are frequently calculated based on body weights of the patients. The double check program includes structured dose calculation support based on patient-specific variables such as ages and body weights of the patients, which likely contributed to the observed reduction in dose verification errors. Previous studies have similarly demonstrated that computerized dose verification systems significantly improve medication safety and reduce calculation-related errors[9].

Similarly, the statistically significant reduction observed in preparation errors after adjustment for multiple comparisons suggests improved adherence to safe medication preparation practices. Medication preparation is recognized as a critical step in preventing medication errors, particularly in pediatric care settings where drug dilution and dosage adjustments are commonly required. The integration of structured preparation guidance into the web-based double check program may have contributed to improved compliance with recommended preparation procedures.

Another important finding was the statistically significant reduction in failure rates in the assessment of vital signs before and/or after administration of medications. Patient monitoring, including the assessment of vital signs, is an essential component of safe medication administration, particularly for high-risk medications that may affect cardiovascular or respiratory function. The inclusion of structured reminders and patient monitoring prompts within the double check program likely supported improved compliance with patient monitoring protocols.

Although reductions in medication route verification errors, monitoring errors, and overall medication error rates, were observed these differences did not remain statistically significant after adjustments made for multiple comparisons. These findings suggest that while improvements occurred in these areas, the magnitude of change may not have been sufficient to demonstrate statistical significance after controlling for multiple testing. Similar observations have been reported in previous studies indicating that certain medication safety improvements may require longer implementation periods or additional supportive interventions to achieve statistically significant outcomes[15,18-23,33,34].

Several other medication error types, including medication time, drug dilution, infusion rate, and documentation-related errors, also demonstrated numerical reductions following the intervention; however, these changes did not reach statistical significance. These findings suggest that while technological and procedural interventions can improve safety in specific high-risk steps, some medication errors may remain influenced by environmental and organizational factors such as workload intensity, staffing levels, and time constraints. Previous studies have similarly identified system-level factors as important contributors to medication errors despite the implementation of technological support systems[5,11,13,34,35].

No wrong patient or wrong medication errors were observed during either the pre- or post-intervention periods. This finding may be associated with the routine use of patient identification practices, including wristband verification and cross-checking procedures, which are considered essential components of safe medication administration. The consistent application of patient identification protocols is widely recognized as a critical factor in preventing high-risk medication errors.

When compared with the relevant literature data, medication error rates reported in observational studies vary widely depending on methodology and setting. Previous studies indicated that medication error rates show substantial variability depending on clinical context and methodological approaches[6-11]. Similarly, error rates for specific types such as dosing errors, timing errors, and infusion-related errors also show substantial variability[33,35]. The relatively high pre-intervention error rates observed in this study are consistent with the known vulnerability of pediatric medication processes[9]. However, significant reduction was observed in pre-intervention error rates after the intervention aligned with findings from studies evaluating structured and technology-assisted safety interventions[18-23,32].

Despite these positive findings, the results should be interpreted with caution. Due to the single-group pre–post study design, it is not possible to attribute the observed improvements solely to the intervention used. Alternative explanations such as the Hawthorne effect (increased awareness due to observation), learning effects over time, or increased attention to medication safety during the study period may have contributed to the observed reductions in medication errors. Therefore, causal inferences are limited, and conduction of future studies using randomized controlled designs is recommended.

In addition, since we focused mainly on medication administration events rather than malpractices of nurses, several observations were obtained from the same participants. This repeated-measures structure may have introduced intra-nurse clustering, whereby medication administrations performed by the same nurse could be more similar to each other than to those performed by different nurses. As clustering was not accounted for in the statistical analysis, standard errors may have been underestimated and some p-values may appear more precise than they truly are. Accordingly, the magnitude and statistical significance of the intervention effect should be interpreted cautiously. Future studies should consider analytic approaches such as mixed-effects models or generalized estimating equations to account for correlated observations.

Another important consideration is that medication error rates were not reduced to zero. This indicates that even with advanced decision support systems, residual errors may persist due to human factors, system constraints, and environmental conditions. Understanding these residual risks is essential for designing more comprehensive patient safety strategies.

Overall, the findings suggest that the web-based double check program improved medication safety by transforming key steps of the medication administration process-particularly dose verification, preparation standardization, and administration guidance. The most striking improvements were observed in high-risk and calculation-dependent steps, supporting the role of decision support systems in reducing cognitive burden and enhancing the importance of clinical decision-making process.

The inclusion of 95% CIs enhances the interpretability and clinical relevance of the findings by providing an estimate of the precision of the observed error rates. These findings highlight the importance of integrating digital decision support systems into pediatric clinical practice to enhance medication safety and reduce the rates of preventable errors.

Study Limitations

This study has several limitations that should be considered when interpreting the results.

First, the quasi-experimental single-group pretest-posttest design without a control group limits the ability to establish a causal relationship between the intervention and the observed reduction in medication error rates. Although a significant decrease was observed in medication error rates following the implementation of the web-based double check program, alternative explanations such as the Hawthorne effect, increased awareness of medication safety, and learning effects over time cannot be disregarded.

Second, medication administration errors were assessed using a non-participant observational method. While this approach is considered one of the most reliable methods for detecting medication errors[6], the presence of an observer may have influenced nurses' behaviors and led to temporary improvements in their performances.

Third, the unit of analysis in this study was medication administration events rather than individual nurses. Since multiple medication administrations were observed for the same nurses, observations may not have been fully independent. This potential intra-nurse clustering could have resulted in underestimated standard errors and inflated their statistical significance. Since clustering was not accounted for analytically or in the sample size calculations, the precision of the estimated intervention effects should be interpreted with caution.

Fourth, although training and a pilot phase were conducted prior to implementation of the study, detailed adherence data, such as frequency, completeness and duration of use, or deviations from intended use, were not systematically recorded. Therefore, it cannot be fully determined whether all nurses consistently used the system for all eligible medication administrations or whether variations in compliance may have affected the outcomes.

Fifth, the study was conducted in a single center and a relatively small number of nurses working in pediatric surgical units participated in the study which may limit the generalizability of the findings to other clinical settings, specialties, or healthcare systems.

Sixth, some contextual and system-related factors known to influence medication errors—such as nurse-to-patient ratios, workload, interruptions, and organizational conditions—remained unchanged during the study period. These factors may explain why certain types of medication errors were not completely eliminated despite the intervention.

Finally, technical limitations related to the web-based nature of the program should be acknowledged. The system required stable internet access, and potential connectivity issues which may have affected its usability in certain situations.

Despite these limitations, the study provides valuable evidence on the potential of computerized decision support systems to improve medication safety in pediatric settings. Conduction of future studies using randomized controlled designs, multi-center samples, and detailed adherence to patient monitoring is recommended to strengthen the evidence base of the study.

Additionally, the use of arithmetic averaging across heterogeneous error categories may have limited the sensitivity of the overall error rate to reflect clinically significant differences between specific error types.

CONCLUSION

This study demonstrated that the implementation of a web-based double check program, developed as a computerized decision support system, significantly reduced medication error rates in administration of high-risk medications for pediatric patient populations.

The medication error rates decreased from 47.8% before the intervention to 19.4% after the intervention, indicating a substantial improvement in medication safety. Reductions in medication error rates were particularly evident in preparation of medications, patient monitoring, and dose verification processes. These findings suggest that integrating computerized decision support systems into clinical practice can effectively support nurses in critical steps of medication administration and reduce the risk of errors.

This program contributed to patient safety primarily through automated dose control, guidance to standardized drug preparation, administration, and implementation of structured double-check mechanisms. These features helped minimize calculation errors, improve adherence to safe medication practices, and reduce variability in clinical implementations.

However, due to the quasi-experimental single-group design, causal conclusions are limited. Conduction of future studies with controlled and randomized designs is needed to confirm these findings and to evaluate their long-term effectiveness.

In addition, the persistence of certain error types indicates that technological solutions should be complemented with organizational improvements such as workload management, staffing optimization, and workflow redesign.

In conclusion, computerized decision support systems such as the web-based double check program represent a promising and feasible approach to improving medication safety in pediatric settings. Their integration into hospital information systems and wider clinical use may contribute to reducing medication errors and enhancing patient safety outcomes.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Ege University Faculty of Medicine Clinical Research Ethics Committee (decision no: 17-11/37, dated: 14.11.2017), and institutional permission was obtained from the hospital where the study was conducted (decision no: 299596, dated: 21.11.2017). The study was retrospectively registered at ClinicalTrials.gov (NCT06371690; 15.04.2024).

Informed Consent: After the necessary explanations were given to the nurses included in the study about the purpose of the research, the method of application and the planned results, written consent was obtained for their participation.

Declaration of AI Use: The authors declare that no generative artificial intelligence (AI) tools were used in the writing of this manuscript or in the analysis or interpretation of the study data.

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This study is based on the author's doctoral thesis completed in 2018. During the preparation of this manuscript, statistical analyses were re-evaluated and updated in accordance with the recommendations of the reviewers. Consequently, some p-values differ from those reported in the original thesis.

Footnotes

This study was based on the doctoral thesis titled "The effects of using the web-based double eye control program on medication of high risk drugs in pediatric patients", registered at the Council of Higher Education Thesis Center, numbered "531551", prepared by Beste Özgüven Öztornacı under the supervision of Prof. Dr. Zümrüt Başbakkal (available from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp).

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Author Contributions

Concept: B.Ö.Ö., Z.B., Design: B.Ö.Ö., Z.B., Supervising: Z.B., Data Collection and Processing: B.Ö.Ö., Analysis and Interpretation: B.Ö.Ö., Z.B., Literature Search: B.Ö.Ö., Writing: B.Ö.Ö., Z.B.

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