Orkaby *et al. BMC Nursing* (2025) 24:382
https://doi.org/10.1186/s12912-025-03034-8

BMC Nursing

RESEARCH Open Access

Bridging generational gaps in medication safety: insights from nurses, students, and generative AI models

Brurya Orkaby[1,2], Erika Kerner[3], Mor Saban[3*†] and Chedva Levin[1,4†]

Abstract

Background This study investigated medication dose calculation accuracy among nurses, nursing students, and Generative AI (GenAI) models, examining error prevention strategies across generational cohorts.

Methods A cross-sectional study was conducted from June to August 2024, involving 101 pediatric/neonatal nurses, 91 nursing students, and four GenAI models. Participants completed a questionnaire on calculation proficiency and provided recommendations for error prevention. Qualitative responses were analyzed to describe attitudes and perceptions.

Results 70% of nurses reported previous medication errors compared to 19.5% of students. Thematic analysis identified six key areas for error prevention: double-checking, calculation methods, work environment, training, drug configuration, and technology use. Only students recommended GenAI integration, while nurses emphasized double-checking.

Conclusions The study highlights generational differences in medication safety approaches and suggests potential benefits of incorporating GenAI as an additional verification layer. These findings contribute to improving nursing education and practice through technological advancements while addressing persistent medication calculation challenges.

Keywords Artificial intelligence, Medication calculation, Prevention, Medication errors, Nursing education

†Mor Saban and Chedva Levin have contributed equally to this study.

*Correspondence:
Mor Saban
morsaban1@tauex.tau.ac.il
[1]Faculty of School of Life and Health Sciences, Nursing Department, The Jerusalem College of Technology-Lev Academic Center, Jerusalem, Israel
[2]The Department of Hemodialysis Children, Shaare Zedek Medical Center, Jerusalem, Israel
[3]Department of Nursing, School of Health Professions, Faculty of Medical and health Sciences, Tel Aviv University, Tel Aviv, Israel
[4]The Department of Vascular Surgery, The Chaim Sheba Medical Center, Tel Hashomer, Tel Aviv, Israel

Background

In the contemporary healthcare landscape, the prevalence of medical errors, particularly in dose calculation, poses significant risks to patient safety and quality of care. Medication dosage miscalculations are unfortunately common and often go unnoticed. These errors can lead to serious patient harm, with estimates suggesting that 7000–9000 people die each year in the US as a result of medication errors [1].

Medication errors pose critical need for standardized recommendations as a global priority to ensure the best and safe practices. Nurses, as frontline professionals in clinical settings, play a pivotal role in medication

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

administration that can lead to unsafe care. challenge. To ensure safe practice, standardized guidelines are essential, encompassing education and training, independent double-checks, adherence to the “five rights” of medication administration, thorough documentation, open communication, and patient education about the drugs they receive. Additional measures include following strict guidelines, improving labeling and packaging formats, addressing work environment challenges, reducing workload, minimizing distractions, fixing systemic flaws, enhancing job security for nurses, and fostering a blame-free workplace culture [1, 2].

Cognitive Load Theory, developed by Sweller, 2020 [3] focuses on the limitations of human working memory when learning complex tasks. It identifies three types of cognitive load: intrinsic (task complexity), extraneous (unnecessary distractions), and germane (productive cognitive effort). In the context of drug dose calculations, errors often arise when intrinsic load is high due to complex calculations or unfamiliar drugs, and extraneous load increases from poorly designed systems or distractions. When cognitive resources are overloaded, it becomes harder for healthcare professionals to process and integrate necessary information, leading to mistakes.

In addition, generational differences among nurses—specifically, those belonging to Generations X, Y, and Z—further highlight shifts in technological proficiency and adaptability. Generation X nurses tend to rely on traditional methods and personal experience when solving problems, while Generation Y (Millennials) embraces technology and collaborative approaches, often utilizing digital tools and social media for problem-solving and patient care [4]. Generation Z, the newest cohort in the workforce, displays a strong inclination towards technology, frequently preferring data-driven solutions and AI tools to enhance their clinical practice [5].

This generational shift influences not only how nurses approach patient care but also underscores the varying levels of comfort and skill with technology across these groups. Younger nurses, particularly those from Generation Y and Z, are generally more adept at utilizing technology, including Generative Artificial Intelligence (GenAI) tools, which can assist in minimizing errors in dose calculations. However, the specific impact of generational differences on dose calculation practices warrants further empirical investigation.

The importance of double-checking calculations cannot be overstated, as it serves as a fundamental safety mechanism in nursing practice. Research indicates that systematic verification processes can significantly reduce the incidence of medication errors [6]. Current strategies to minimize error in patient care, particularly in medication dosing, foster implementing double-check systems, using calculators, and adopting specific technologies designed to ensure accuracy [7]. For instance, employing computerized physician order entry (CPOE) systems and electronic health records (EHRs) can streamline the medication administration process and reduce the likelihood of human error [8].

Overreliance on AI systems in drug dose calculations presents several risks. While AI can enhance accuracy, it is only as reliable as the data it is trained on, and incorrect or biased data can lead to harmful dosing errors [9]. Nurses may become complacent, trusting AI results without sufficient critical evaluation, which could erode their decision-making skills [10]. Additionally, AI systems depend on constant updates and maintenance, and any lapses could compromise safety [9]. Privacy concerns and challenges in algorithm transparency also raise issues regarding accountability when errors occur. To minimize these risks, AI should be viewed as a supportive tool rather than a replacement for clinical judgment, with ongoing training, regular system checks, and human oversight to ensure safety and effectiveness in drug dosing [11].

Furthermore, the integration of AI into nursing education and practice offers innovative solutions to enhance clinical competencies. GenAI can provide simulations and practice scenarios that allow nursing students to hone their skills before entering the clinical environment, thereby reducing the likelihood of errors in real-world settings [12]. The current use of GenAI and language models in healthcare presents significant benefits, particularly in minimizing dosing errors. GenAI systems can assist nurses in calculating dosages accurately by providing real-time data analysis and recommendations based on patient-specific parameters [13].

Additionally, GenAI can serve as a valuable educational tool for nursing students, offering interactive learning experiences that reinforce correct calculation methods and enhance their understanding of pharmacology [14]. By integrating GenAI into nursing curricula, educational institutions can better prepare future nurses to navigate the complexities of medication administration in a technology-driven healthcare environment [15].

The aim of this article outlines how to reduce medication calculation errors, based on recommendations from nurses, students, and GenAi models systems. The findings of this study, as part of larger quantitative research, are intended to contribute to the ongoing discourse on improving nursing education and practice through technological advancements.

Ultimately, the findings may offer insights into how GenAI can be effectively integrated into nursing workflows to ensure patient safety and care quality. The significance of this research lies in its potential to inform best practices in nursing education and clinical practice, ensuring that nurses are equipped with the necessary skills and tools to minimize medication errors and improve patient outcomes. While the AI benefits have been identified, yet application of AI tools must be carefully implemented to ensure accuracy and safety.

Methods

Design

Between June and August 2024, a cross-sectional study was conducted. The data collection instrument was comprised of a three-part questionnaire: the first section included nine items assessing participants' proficiency in calculating accurate medication dosages for patient administration; the second section investigated whether respondents had previously encountered errors in pharmaceutical calculations when dispensing medications to their patients. The third section contained an ioen question asking for recommendations on strategies to prevent calculation errors in medication administration.

Questionnaire development

The questionnaire used in this study was developed specifically for this research by two PhD-level nurses. These nurses work in the Pediatric Department and the Intensive Care Unit, and serve as nursing faculty members in a BSN training program. The questions are based on common medications administered in their respective departments and reflect real-world scenarios encountered by nursing students and practicing nurses. Their dual roles as clinical practitioners and educators provide unique insights into the medication calculations needed in daily hospital practice and the essential computational skills nursing students must master. An English language version of the questionnaire is provided as a supplementary file.

Participants

The study encompassed six distinct cohorts: pediatric and neonatal nurses, undergraduate nursing students from the second through fourth years of a four-year program, and four GenAI models (1) ChatGPT-4, (2) Claude-3.0, (3) Open AI o1, and (4) LLAMA 3 8b). For the human participants, demographic information was collected. Nurses provided details on their gender, age, years of experience, specific pediatric department, academic status, and basic training. Students disclosed their gender, age, current year of study, and nursing-related work experience.

Data collection

The study protocol was standardized across all participant categories, including both human subjects and GenAI models. The core assessment comprised nine medication calculation questions. Subsequently, participants were invited to provide suggestions for eliminating calculation errors in the process of medication administration. Human respondents were additionally asked to indicate whether they had previously made an error in calculating a medicinal dose.

The assessment tool was developed by two principal investigators, both experienced nurses with over 25 years of clinical practice and doctoral qualifications. Their extensive clinical backgrounds enabled them to design a questionnaire that accurately captures the computational tasks nurses encounter daily, while adhering to current healthcare standards.

Qualtrics XM digital survey platform was utilized for the data collection. In addition, the study incorporated four state-of-the-art language processing systems: OpenAI's ChatGPT-4 and o1, Claude 3.5 Sonnet, anthropic's AImodel, and Meta AI's Llama 3 8B. This diverse selection of AI models, each with unique architectural designs and training methodologies, facilitated a comprehensive evaluation of machine learning capabilities in pharmaceutical calculations. ChatGPT-4 is renowned for its advanced linguistic processing and complex problem-solving abilities. Claude 3.5 Sonnet specializes in nuanced communication and precise language tasks. OpenAI's o1 represents a new generation of language models with enhanced reasoning and mathematical proficiency. Llama 3 8B, an open-source alternative, has demonstrated notable potential across various linguistic comprehension and generation tasks.

Data analysis

This paper focuses on the data of the open question in the questionnaire seeking recommendations to ensure safe dosing calculation when administering medications to patients. A qualitative approach was applied to analyze the data from the participants' answers. Thematic analysis was applied. The process began with a thorough review of all suggestions, by both authors independently. They then collaborated to identify repetition of key concepts within the responses. This process led to the development of distinct categories, each representing a unique strategy for preventing errors.

The definition of the themes was created in collaboration with a team of researchers, ensuring agreement on the topics. The authors refined these categories through several discussions, reaching a consensus on the final groupings. Throughout the analysis, the researchers revisited the original information to ensure that nothing was taken out of context. To strengthen the analysis, the researchers quantified how often each category appeared across different participant groups.

The resulting categorization not only highlighted common themes in error prevention strategies but also revealed potential differences in perspectives between human participants and GenAI models, offering valuable insights for improving medication safety protocols.

Ethics approval and consent to participate

The research was initiated after obtaining formal approval from Tel Aviv University's ethical review board (0006223–2). The research team implemented strict measures to ensure the confidentiality of all participants throughout the data collection process. Human subjects, including both practicing nurses and nursing students, were thoroughly briefed on the study's objectives and procedures. Participation was entirely voluntary, with everyone providing informed consent.

This study was conducted in full compliance with the ethical principles outlined in the Declaration of Helsinki. A key aspect of the ethical framework was the emphasis on participants' autonomy. All subjects were clearly informed of their right to withdraw from the study at any time, without needing to justify their decision.

Results

The sociodemographic characteristics of the study's human participants are summarized in Table 1, comparing nursing students (N = 91) with pediatric and neonatal nurses (N = 101). Nursing students had an average age of 25.4 years (SD = 5.26), whereas practicing nurses had a higher mean age of 37.4 years (SD = 9.68). The average nurses' years of experience was 11.28 years (SD = 9.82).

In terms of gender distribution, most of both groups were female, with 83.7% of students and 95% of nurses identifying as women. The nursing students were evenly distributed across academic years: 31.5% were in their second year, 32.6% in their third year, and 35.9% in their fourth year. Among nurses, 75.2% held a B.A. degree, while 24.8% had an M.A.

Regarding work experience, 41.3% of students reported having some nursing assistance experience, while 64.4% of nurses had completed post-basic courses. Most nurses (70%) reported having made a medication calculation error during their work, compared to 19.5% of students who reported errors during their nursing studies.

Table 2 summarizes recommendations for preventing errors in medication calculations, gathered from study participants, including nurses, students, and GenAI models. The recommendations are organized around several central themes, each featuring specific suggestions from various perspectives. Key sub-themes include double-checking procedures, calculation methods, work environment considerations, training exercises simulations, drug configuration, and the use of technology in medication management.

The recommendations range from practical advice, such as using calculators and clearly writing out calculations, to systemic changes like reducing work load and implementing regular training sessions.

Figure 1 provides a visual summary of recommendations for preventing medication errors, organized into six key themes: Double Check, Method of Calculation, Work Environment, Exercises, Drug Configuration, and Use of Technology. Under each theme, the specific groups (GenAI models, Nursing Students, and/or Pediatric and Neonatal Nurses) that contributed recommendations within that category are listed, based on the qualitative responses from the participants.

For example, the Double Check theme includes recommendations from all three groups—GenAI models, Nursing Students, and Nurses. In contrast, the Work Environment theme only includes recommendations from the GenAI models and Nurses, as Nursing Students did not provide any suggestions within that category. Similarly, the Use of Technology theme was recommended by the GenAI models and Nursing Students, but not by the Nurses.

Additionally, the Drug Configuration theme stresses that all GenAI models except for LLAMA made recommendations for this category.

Discussion

The findings of this study highlight challenges in medication calculation accuracy among nurses. A significant number of nurses reported having made medication calculation errors in the past. 70% of nurses acknowledged

Table 1 Sociodemographic characteristics of the human study sample

Variable	Nursing students (N-91)		Nurses (N – 101)	
Age mean (SD)	25.4 (5.26)		37.4 (9.68)	
Seniority (year)	–		11.28 (9.82)	
Variable			N (%)	
Gender				
Male	15(16.3)		5 (5)	
Female	77 (83.7)		96 (95)	
Academic year/Academic status	Second year	29 (31.5)	B. A	76 (75.2)
	Third year	30 (32.6)	M.A	25 (24.8)
	Fourth year	33 (35.9)		
Student work in nursing/Post basic course	Yes	38 (41.3)	Yes	65 (64.4)

Table 2 Central themes and quotes for research participants' recommendations to prevent errors in medication calculation

Theme	Sub theme	Nurses	Students	Claude 3.5	ChatGPT-4.0	Open AI o1	LLAMA 3 8b
Double check		"It's crucial to maintain strict double-checking of medications, especially in pediatric wards. Don't show the calculation result to the reviewing nurse, so she can perform her own calculation independently. This is true quality control!" (Nurse #9)	"Ask another people to do the calculation and then compare answers." (Student #38) "Share your calculation with someone else." (Student #58)	Double check	Double check	Double check	Double check
Method of calculation	Calculator	"Always use a calculator." (Nurse #39) "Make sure to perform calculations using a calculator and don't rely on memory." (Nurse #71)	"Emphasize the use of a calculator." (Student #3).	Use of calculators	Use of calculators	Use of calculators	Use of calculators
	Triple value		"Teach 'Triple value' simply." (Nurse #10)			Adopt universal calculation methods: Use a consistent approach, such as the "dimensional analysis" or "ratio-proportion"	
	Calculation tools		"Organized tables in the medication room showing common dosages." (Student #83) "Place paper, pens, and calculators in the medication room. Also, hang a chart showing and reminding of the relationships between different measurements (grams, mg, mcg, liters, ml, etc.)." (Student #59)	Built in protocols to follow, checklists Ready to use calculated doses Visual aids	Built in protocols to follow, checklists	Provide nurses with pocket guides, reference charts Ready to use calculated doses Visual aids	Calculation sheets or worksheets
	Double calculation		"Always recalculate and don't rely on memory, even for medications that are frequently used." (Student #8)				
	Calculation on the page (written)	"Write calculations on paper and don't do them in your head, even if you're familiar with the medication." (Nurse #57) "Paper and pen, calculator, written instructions" (Nurse #78)	"Don't do calculations in your head and don't prepare medications out of habit." (Student #52)				Provide calculation sheets or worksheets that can be used to perform calculations

Table 2 (continued)

Theme	Sub theme	Nurses	Students	Claude 3.5	ChatGPT-4.0	Open AI o1	LLAMA 3 8b
Work environment		"Remove work pressure" (Nurse #34)		Safe environment to ask questions Safe environment to report mistakes Quiet place to calculate	Safe environment to ask questions	Safe environment to ask questions	Foster a culture of safety and transparency, encouraging staff to speak up if they notice an error or concern
Exercises		"Conduct regular practice exercises and tests, even for experienced staff." (Nurse #22) "Update competency test questions and make them relevant to the specific department." (Nurse #32)	"Practice, practice, practice. Both theoretical and practical." (Student #10) "Try to teach nursing calculations through logical thinking rather than relying solely on formulas." (Student #68)	Training for the staff Periodical simulations	Training for the staff Periodical simulations	Training and Pharmacology refreshers: Periodical simulations	Pharmaceutical calculation training
Drug configuration		"Consistent dilution of medication across different pharmaceutical companies. Small vials for very high-risk medications." (Nurse No. 69)		Clear labelling of medication name, dose Standard units for all medication and calculation	Clear labelling of medication name, dose	Reference charts: Provide laminated dosage calculation charts for common medications at nurses' stations	
Use of technology			"Software that calculates the dosage according to the medication available in the department, which comes after the calculation for self-verification." (Student No. 4) "Software/application that allows data input and calculates the dosage. (Including rate, etc…)" (Student No. 24)	Use digital tools or apps designed	Utilize calculation apps and electronic medical records	Mobile apps	Utilize technology, such as calculators or mobile apps

having made such errors, compared to only 19.5% of nursing students. This discrepancy is understandable given the greater frequency with which nurses perform calculations in their daily practice, as well as the complexities of their work environment [16].

Furthermore, Cognitive Load Theory explains the challenges faced in clinical settings during drug dose calculations, highlighting how the use of cognitive resources in problem-solving tasks, along with the limitations of working memory, can impact performance in complex calculations and potentially lead to errors. These challenges are exacerbated by the demanding nature of nurses' work, including 24/7 shifts, night shifts, and the associated fatigue and drowsiness, which further increase extraneous cognitive load. Fatigue-related cognitive strain may impair working memory capacity, slowing down processing speed and increasing the likelihood of miscalculations. In this context, AI-based decision-support tools may play a crucial role in reducing cognitive burden, particularly in high-pressure situations where nurses must make rapid and accurate medication-related decisions [3].

Interestingly, nurses placed a strong emphasis on the importance of double-checking procedures in their recommendations, in contrast to students who highlighted the significance of practical training exercises. This focus from nurses is logical, given their professional experience and the need for reliable practices that mitigate errors [17].

The recommendation for double-checking is especially important, as it highlights the value of incorporating GenAI as an additional layer of verification in medication administration. This could help prevent errors not only in high-risk situations but also in routine practices that currently require double-checking. Among students, who generally lack extensive practical experience, there was a strong emphasis on the need to acquire relevant knowledge while integrating innovative technologies for calculating medication dosages.

It is noteworthy that only students mentioned the use of GenAI in their recommendations. This suggests a gap in awareness or acceptance of technological solutions among practicing nurses, who may benefit from training that integrates these tools into their workflows. However, it is important to consider the potential drawbacks of using the proposed AI system, ensuring that it assists and complements, rather than replaces, nurses' fundamental understanding of drug calculations. The system is not intended to bypass the critical thinking process of the healthcare team, but to serve as a supportive tool that enhances work efficiency and reduces errors. It is essential to emphasize that professionals should remain actively involved in the decision-making process, ensuring that the recommendations generated by the system are reviewed and manually approved before implementation [11]. Additionally, safeguards should be in place to require nurses to demonstrate their understanding of calculations before using artificial intelligence tools [10].

Furthermore, there was minimal reference among nurses to the importance of drug configuration—an aspect well-documented in the literature as critical for error prevention. This lack of attention may indicate either a gap in knowledge or a disconnect between theory and practice in real-world settings [18].

One nurse's comment about double-checking, delivered with a hint of irony, suggesting that despite its recognized importance, this practice is not consistently implemented. This raises concerns about adherence to protocols, which may contribute to the frequency of calculation errors. The necessity for clear written guidelines and consistent practice is evident, as is the need for ongoing education and training to reinforce these practices [19].

An important consideration is how we framed our questions to students regarding their past experiences with medication calculation errors. Asking them if they had made such errors "as nurses" could be misleading, as they are still in training and not yet licensed professionals. This highlights the need for careful wording in survey instruments to accurately capture relevant experiences without misrepresenting participants' statuses.

When comparing the recommendations from nurses and students to those generated by GenAI models, it is essential to assess whether there are novel insights or approaches. While nurses tended to propose more practical solutions, students may have offered innovative ideas that reflect their recent academic training. Understanding these differences could inform the development of more effective training programs for both groups, emphasizing the integration of practical skills and technological advancements.

Finally, the successful integration of AI-based decision-support tools into nursing practice is not solely a technical challenge but also a collaborative effort requiring input from multiple disciplines. While nurses and educators play a crucial role in guiding the digital transformation of nursing, researchers in healthcare informatics and engineers specializing in AI and automation must also be actively involved. Effective workflow automation, as discussed by Zayas-Cabán et al. [20], depends on structured collaboration among these stakeholders to align technological advancements with real-world clinical demands. By fostering interdisciplinary partnerships, healthcare institutions can enhance AI adoption, improve medication safety, and optimize nursing workflows, ultimately reducing cognitive burden and improving patient outcomes.

Limitations

This study has several limitations that should be acknowledged. First, the sample size, while adequate, may not fully represent the broader population of nursing fields of expertise. Additionally, the reliance on self-reported data may introduce bias, as participants could underreport or overreport their experiences with medication calculation errors. Furthermore, the study's cross-sectional design limits the ability to draw causal inferences about the effectiveness of recommended strategies.

Another limitation is the potential for variability in the interpretation of questions related to past experiences. The phrasing used may not have accurately captured the experiences of nursing students, leading to potential misunderstandings in their responses. Another limitation, in the context of using artificial intelligence for drug dosage calculations, is the need to consider technical limitations and potential failure scenarios. This highlights the importance of safety checks and human oversight to ensure the system's reliability.

Conclusion

In conclusion, addressing the ongoing issue of medication calculation errors requires a multifaceted approach that includes enhancing training, improving adherence to double-checking protocols, and integrating GenAI models. By fostering a culture of safety and continuous learning, we can better equip nursing professionals to minimize errors and improve patient outcomes.

Future research should explore the effectiveness of specific interventions and training programs designed to integrate technological solutions into nursing practice, with the goal of enhancing medication safety in clinical settings. Additionally, existing global practices aimed at reducing errors in drug dosage calculations should be thoroughly examined.

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-025-03034-8.

Supplementary Material 1

Acknowledgment
None.

Author contributions
Study design: MS and CL; Data collection: BO; Data analysis: BO, EK; Manuscript writing: MS, CL, BO, EK; Critical revisions for important intellectual content: MS, CL, BO, EK.

Funding
This research received no grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethical approval
The research was initiated after obtaining formal approval from Tel-Aviv University's ethical review board (#0006223-2). The research team implemented strict measures to ensure the confidentiality of all participants throughout the data collection process. Human subjects, including both practicing nurses and nursing students, were thoroughly briefed on the study's objectives and procedures. Participation was entirely voluntary, with each participant providing informed consent.

Informed consent to participate
was obtained from all subjects. This study was conducted in full compliance with the ethical principles outlined in the Declaration of Helsinki. A key aspect of the ethical framework was the emphasis on participants' autonomy. All subjects were clearly informed of their right to withdraw from the study at any time, without needing to justify their decision.

Consent for publication of identifying patient information
Not applicable.

Authorship
We confirm that all authors meet the following four criteria: Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND Drafting the work or revising it critically for important intellectual content; and Final approval of the version to be published; AND Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests
None.

Received: 19 October 2024 / Accepted: 25 March 2025
Published online: 07 April 2025

Reference

1. Alrabadi N, Shawagfeh S, Haddad R, et al. Medication errors: a focus on nursing practice. J Pharm Health Serv Res. 2021;12(1):78–86. https://doi.org/10.1093/JPHSR/RMAA025.
2. Abbasi S, Rashid S, Khan FA. A retrospective analysis of peri-operative medication errors from a low-middle income country. Sci Rep. 2022;12(1):1–8. https://doi.org/10.1038/s41598-022-16479-7.
3. Sweller J. Cognitive load theory and educational technology. Edu Technol Res Dev. 2020;68(1):1–16. https://doi.org/10.1007/S11423-019-09701-3/TABLES/1.
4. Shinners L, Aggar C, Grace S, Smith S. Exploring healthcare professionals' understanding and experiences of artificial intelligence technology use in the delivery of healthcare: an integrative review. Health Inf J. 2020;26(2):1225–36. https://doi.org/10.1177/1460458219874641.
5. Secinaro S, Calandra D, Secinaro A, Muthurangu V, Biancone P. The role of artificial intelligence in healthcare: a structured literature review. BMC Med Inform Decis Mak. 2021;21(1):1–23. https://doi.org/10.1186/S12911-021-01488-9/FIGURES/12.
6. Jha N, Shankar PR, Al-Betar MA, Mukhia R, Hada K, Palaian S. Undergraduate medical students' and interns' knowledge and perception of artificial intelligence in medicine. Adv Med Educ Pract. 2022;13:927–37. https://doi.org/10.2147/AMEP.S368519.
7. Rony MKK, Parvin MR, Wahiduzzaman M, Debnath M, Bala SD, Kayesh I. "I wonder if my years of training and expertise will be devalued by machines": concerns about the replacement of medical professionals by artificial intelligence. Sage Open Nurs. 2024. doi:https://doi.org/10.1177/23779608241245220.
8. Karim S. The challenges and opportunities of adopting artificial intelligence (AI) in Jordan's healthcare transformation. Glob J Inf Technol Emerg Technol. 2021. doi:https://doi.org/10.18844/gjit.v11i2.6546.
9. Wang X, Zhang NX, He H, et al. Safety challenges of AI in medicine. Published online September 11, 2024. Accessed December 28, 2024. https://arxiv.org/abs/2409.18968v1
10. Uygun Ilikhan S, Özer M, Tanberkan H, Bozkurt V. How to mitigate the risks of deployment of artificial intelligence in medicine? Turk J Med Sci. 2024;54(3):483–92. https://doi.org/10.55730/1300-0144.5814.
11. Bartlett B. The possibility of AI-induced medical manslaughter: unexplainable decisions, epistemic vices, and a new dimension of moral luck. 2023; 23(3):241–70. https://doi.org/10.1177/09685332231193944.
12. Hee Lee D, Yoon SN. Application of artificial intelligence-based technologies in the healthcare industry: opportunities and challenges. Int J Environ Res Public Health. 2021;18(1):1–18. https://doi.org/10.3390/IJERPH18010271.
13. Petersson L, Larsson I, Nygren JM, et al. Challenges to implementing artificial intelligence in healthcare: a qualitative interview study with healthcare leaders in Sweden. BMC Health Serv Res. 2022;22(1):1–16. https://doi.org/10.1186/S12913-022-08215-8/FIGURES/1.
14. Salah HT, Muhsen IN, Salama ME, Owaidah T, Hashmi SK. Machine learning applications in the diagnosis of leukemia: current trends and future directions. Int J Lab Hematol. 2019;41(6):717–25. https://doi.org/10.1111/IJLH.13089.
15. Safi S, Thiessen T, Schmailzl KJG. Acceptance and resistance of new digital technologies in medicine: qualitative study. JMIR Res Protoc. 2018;7(12):e11072. https://doi.org/10.2196/11072.
16. Härkänen M, Vehviläinen-Julkunen K, Murrells T, Paananen J, Franklin BD, Rafferty AM. The contribution of staffing to medication administration errors: a text mining analysis of incident report data. J Nurs Schol. 2020;52(1):113–23. https://doi.org/10.1111/JNU.12531.
17. Yousef A, Abu Farha R, Da'meh K. Medication administration errors: causes and reporting behaviours from nurses perspectives. Int J Clin Pract. 2021;75(10):e14541. https://doi.org/10.1111/IJCP.14541.
18. Singh K, Alomari AMA, Sayed HMA, et al. Barriers and solutions to the gap between theory and practice in nursing services: a systematic review of qualitative evidence. Nurs Forum (Auckl). 2024;2024(1):7522900. https://doi.org/10.1155/2024/7522900.

19. Research Fellow S, Alomari AR, Sheppard-Law MPHSB, et al. Effectiveness of Clinical Nurses' interventions in reducing medication errors in a paediatric ward. J Clin Nurs. 2020;29(17-18)3403–13. https://doi.org/10.1111/JOCN.15374.
20. Zayas-Cabán T, Okubo TH, Posnack S. Priorities to accelerate workflow automation in health care. J Am Med Inf Assoc. 2023;30(1):195–201. https://doi.org/10.1093/JAMIA/OCAC197.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.