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Impact of Mannequin Based Simulation as Add on Teaching Learning Tool in Pharmacology Training of Undergraduate Medical Students

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ABSTRACT

Background: Traditional didactic methods in pharmacology education often fail to actively engage undergraduate medical students or foster clinical application of theoretical knowledge. To bridge this gap, mannequin-based simulation has emerged as a promising educational strategy, offering hands-on, experiential learning in a controlled environment. This study aimed to assess the effectiveness of mannequin-based simulation as an adjunct teaching tool in pharmacology training for second-year MBBS students.

Materials & Methods: A prospective observational study was conducted among 100 second-year MBBS students at Saraswati Medical College, Unnao. Participants underwent mannequin-based simulation training on intravenous (IV), intramuscular (IM), and subcutaneous (SC) drug administration. Student perceptions were evaluated using structured questionnaires, and practical competencies were assessed using pre- and post-simulation Objective Structured Practical Examinations (OSPE). Statistical analysis included paired t-tests, Wilcoxon signed-rank tests, and chi-square tests with a significance threshold of $p < 0.05$.

Results: A strong majority of students (over 85%) expressed favorable perceptions of mannequin-based learning, particularly in enhancing attention span, theoretical integration, procedural skills, and confidence. The post-simulation OSPE scores showed statistically significant improvements in procedural competencies across all three administration routes. For IV training, the paired t-test ($p < 0.001$) and Wilcoxon test ($p < 0.001$) indicated a highly significant improvement. Similarly, significant gains were observed for IM ($p < 0.001$; $p = 0.0156$) and SC ($p = 0.00014$; $p = 0.0313$) routes.

Conclusion: Mannequin-based simulation significantly enhanced student's pharmacological skill proficiency, confidence, and engagement. Its positive reception and measurable impact on learning outcomes support its integration into routine pharmacology curricula to bridge the gap between theory and clinical practice, thereby preparing students for safe, effective patient care.

INTRODUCTION

Pharmacology, a cornerstone subject in undergraduate medical education, plays a pivotal role in shaping future physician's understanding of drug actions, interactions, adverse effects, and clinical applications. Despite its importance, traditional approaches to pharmacology teaching-largely centered on didactic lectures and passive content delivery-often fail to actively engage students or foster deep understanding. These methods, while useful for theoretical grounding, do not provide sufficient opportunities to apply pharmacological knowledge in clinical scenarios, a skill critical for safe and effective prescribing. As medical education evolves to meet the demands of a dynamic healthcare environment, there is growing recognition of the need for active, experiential, and student-centered learning methods that bridge the gap between theory and clinical practice [1,2].

One such method gaining prominence is simulation-based learning. Although it may appear to be a modern innovation due to advancements in digital and technological tools, simulation has long been a part of professional training in other high-risk fields. The aviation and aerospace industries, for instance, have relied heavily on simulators for pilot training for decades. Similarly, simulation tools are widely used in the military, nuclear power plants, commercial airlines, and business sectors to ensure skill development and decision-making under pressure. The adoption of simulation in medical education reflects this broader trend, facilitated by rapid technological progress that has made simulators more accessible and realistic [3,4].

In medical education, simulation provides a structured and risk-free environment where students can acquire essential clinical skills without jeopardizing patient safety. The use of mannequin-based simulation specifically allows learner's to engage with life-like clinical situations, offering practical exposure to pharmacological principles in a controlled setting. In recent years, mannequin-based simulation has been integrated into the pharmacology curriculum for second-year medical students, marking a significant step forward in aligning preclinical subjects with clinical realities. These simulations replicate real-time healthcare settings, enabling students to develop procedural competencies such as drug administration, emergency pharmacotherapy, dose calculations, and the management of adverse drug reactions [5].

The acquisition of procedural skills is an essential competency for a medical graduate. Traditionally, students developed these competencies by observing experienced clinicians during ward rounds and subsequently applying these skills to real patients. While effective to some extent, this model poses inherent risks, particularly in pharmacology, where medication errors can lead to serious patient harm. The challenge lies in ensuring that students can learn and practice these skills without compromising patient safety. Simulation-based medical education addresses this concern by offering repeated, hands-on practice in a safe environment, thus allowing for error, feedback, and correction without any risk to real patients [6,7].

Simulation, by definition, is a method of training that involves replicating clinical scenarios using tools like mannequins, virtual reality, or standardized patients. It incorporates feedback mechanisms through peer reviews, instructor observation, and video analysis to enhance learner performance and confidence. This form of training is especially valuable in developing both cognitive and non-cognitive skills. It promotes decision-making, team collaboration, communication, and situational awareness—all of which are vital for effective clinical practice. Furthermore, the integration of simulation enhances student engagement, motivation, and commitment, leading to improved knowledge retention and skill acquisition [8,9].

The significance of simulation-based teaching was further highlighted during the COVID-19 pandemic, when conventional bedside teaching was restricted. During this time, online and simulated learning emerged as crucial alternatives, underlining the importance of the medium through which knowledge is transferred. Students perception of learning, their satisfaction, self-efficacy, and confidence were found to be positively influenced by simulation-based training, especially when it replaced or supplemented clinical experience that was otherwise unavailable [10].

Beyond pharmacology, the use of simulation spans a wide spectrum of medical disciplines, including anesthesiology, emergency medicine, surgery, and therapeutic decision-making. It has proven particularly beneficial in areas requiring high-stakes decision-making and rapid response, where experiential learning can significantly impact clinical outcomes. Similar to nursing and midwifery education, medical education now recognizes simulation as a valuable complement to real-life clinical experience. It ensures that students are not only theoretically competent but also practically prepared to deliver safe and effective patient care [11].

Incorporating mannequin-based simulation as an adjunct tool in pharmacology education reflects a transformative approach to medical training. It redefines how pharmacological knowledge is taught and applied, providing students with an enriched learning experience that integrates classroom concepts with clinical application. This approach not only reinforces theoretical knowledge but also enhances student's preparedness for future clinical responsibilities. Evaluating the effectiveness of this method is essential to understanding its role in improving educational outcomes, guiding curriculum development, and shaping the next generation of safe, competent, and confident medical professionals [12].

The aim of this study is to assess the effectiveness of mannequin-based simulation as a teaching tool for pharmacology among second-year undergraduate students. The objectives include evaluating student's perceptions of mannequin-based simulation as a teaching method, exploring strategies to enhance the realism and accessibility of the mannequin simulator, and assessing the practical skills of students using the Objective Structured Practical Examination (OSPE) method.

MATERIAL AND METHODS

This prospective observational study was conducted at the Department of pharmacology, Saraswati Medical College, Unnao. Ethical approval has been obtained from the Ethical Approval Committee of Saraswati Medical College, Unnao.

Study Population

The study included 100 second-year MBBS students from Saraswati Medical College, Unnao, Uttar Pradesh. All participants provided informed consent before inclusion in this cross-sectional, observational study. The students underwent mannequin-based simulation training involving three parenteral drug administration routes-intravenous, intramuscular, and subcutaneous. Training sessions were supervised by pharmacology faculty using standardized protocols. This cohort was selected to assess perceptions, practical skills, and confidence improvement following simulation-based learning within a one-month study duration.

Data Analysis

Data were compiled using Microsoft Excel and statistically analyzed using SPSS version 26.0. Pre- and post-intervention scores from Objective Structured Practical Examination (OSPE) checklists were compared using paired t-tests. Wilcoxon Signed-Rank tests were employed to validate non-parametric results. Student's perceptions were recorded via structured questionnaires, and chi-square tests evaluated response distribution. Statistical significance was defined at a p-value less than 0.05 to determine effectiveness of mannequin-based simulation training in enhancing pharmacological skill acquisition.

RESULTS

Our study demonstrated significant student support for mannequin-based simulation. Over 85% of students either agreed or strongly agreed that simulation enhanced attention, integration of theory with clinical practice, procedural skills, and patient safety. Statistical analysis showed all responses had p-values <0.001, indicating highly significant favorability. OSPE results for intravenous, intramuscular, and subcutaneous procedures showed substantial improvement post-simulation with paired t-tests and Wilcoxon signed-rank tests confirming significance (all p-values <0.05). These findings indicate a notable increase in skill competency and student confidence after mannequin-based training, validating its use as an effective teaching tool in pharmacology education.

Table 1: Perception of Students Regarding Mannequin Based Teaching in Pharmacology

S. No	Questionnaire	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Chi Square Value	DF	P-Value
1.	Simulation Practice on Mannequin was a Valuable Use of My Time	35	43	14	4	0	59.38	4	<0.001
		36.5%	44.8%	14.6%	4.2%	0.0%			
2.	It Increased My Attention Span by Active Participation	32	47	13	2	0	63.00	4	<0.001
		33.3%	49.0%	13.5%	2.1%	0.0%			
3.	It Provided Help to Integrate the Theoretical Knowledge and Clinical Problem Solving	31	50	13	2	0	60.87	4	<0.001
		32.3%	52.1%	13.5%	2.1%	0.0%			
4.	Improved My Procedural Skill About Various Routes of Drug Administration	32	52	10	2	0	68.50	4	<0.001
		33.3%	54.2%	10.4%	2.1%	0.0%			
5.	Mannequin Based Simulation is a Useful Tool in Pharmacology Teaching	12	67	10	5	2	59.00	4	<0.001
		12.5%	69.8%	10.4%	5.2%	2.1%			
6.	Repeated Practice on Mannequin Might Help in Safe Administration of Drugs on Patient	49	32	15	0	0	66.12	4	<0.001
		51.0%	33.3%	15.6%	0.0%	0.0%			
7.	Simulation Learning Closely Resemble Real Life Scenario?	41	40	10	4	1	53.75	4	<0.001
		42.7%	41.7%	10.4%	4.2%	1.0%			

8.	Would You Like to Participate in Simulation Learning if Available in Voluntary Basis	50	33	9	3	1	66.00	4	<0.001
		52.1	34.4	9.4	3.1	1.0			

Students overwhelmingly favored mannequin-based simulation in pharmacology, with most responses falling under "Agree" or "Strongly Agree" across all evaluated aspects, including enhanced attention, practical skill improvement, and real-life applicability. Statistical analysis confirmed strong, significant support for this teaching method.

Figure 1: Bar Chart Visualizes the Mean Scores for Each Procedural Skill Before and After Simulation - For Intravenous Injection

OSPE scores for intravenous drug administration showed a marked improvement after mannequin-based simulation training. Both paired t-test and Wilcoxon test confirmed this enhancement was statistically highly significant ($p < 0.001$).

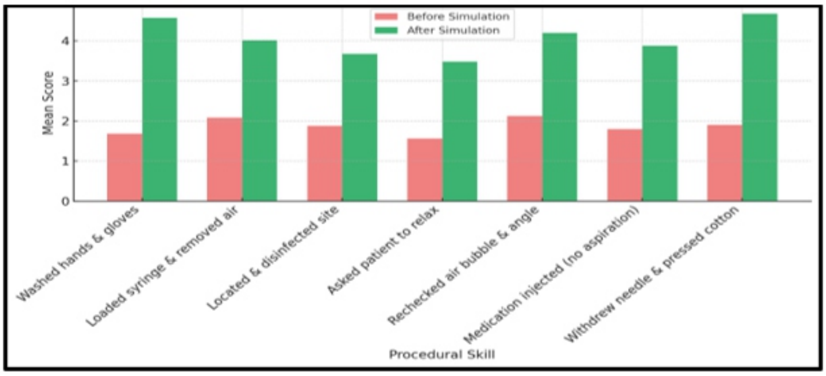

Figure 2: Bar Chart Visualizes Mean Scores Before and After Simulation for Each Skill-Clearly Showing Substantial Gains in Performance- for Intramuscular Injection

Simulation training for intramuscular drug administration led to a statistically significant improvement in procedural skills, as confirmed by both paired t-test ($p < 0.001$) and Wilcoxon test ($p = 0.0156$), showing clear performance gains.

Figure 3: Bar Chart Visualizes Mean Scores Before and After Simulation for Each Skill -Clearly Showing Substantial Gains in Performance- for Subcutaneous Injection

Subcutaneous drug administration skills improved significantly after simulation training, with both Wilcoxon (p = 0.0313) and paired t-test (p = 0.00014) confirming a statistically significant and impactful enhancement in student performance.

DISCUSSION

In our study, students expressed overwhelming support for mannequin-based simulation in pharmacology teaching, with a majority rating the experience as valuable, engaging, and realistic. Specifically, over 80% of students agreed or strongly agreed that simulation improved attention span, integrated theoretical knowledge with clinical reasoning, enhanced procedural skills, and contributed to safer drug administration practices. Each questionnaire item revealed statistically significant support (p < 0.001), confirming students' strong preference for this hands-on learning approach. Similarly, reported that students in the virtual reality high-fidelity mannequin (VHFM) simulation group significantly outperformed those in traditional tutorial groups across pre-test, post-test, and retest evaluations. Their findings also highlighted positive feedback from students regarding VHFM's ability to foster active learning, clinical reasoning, and skill development. Both studies indicate that simulation-based methods, whether through standard mannequins or advanced VHFM, enhance student learning outcomes and engagement compared to conventional teaching. Additionally, emphasized the importance of fidelity in simulation, finding that a high-fidelity mannequin environment boosts student engagement and skill acquisition, while varied levels of fidelity tailored to learner's experience levels can optimize learning and reduce anxiety. When compared, our study aligns well with these findings, reinforcing the view that mannequin-based simulation-regardless of the fidelity level-is a highly effective and student-centered strategy in medical education [13,14].

Our study demonstrated a significant improvement in procedural skills for intravenous drug administration following mannequin-based simulation training, with marked gains in hand hygiene, syringe preparation, site selection, and injection techniques. The effectiveness of this intervention was statistically validated by both the paired t-test and Wilcoxon signed-rank test, with p-values < 0.001, indicating a highly significant enhancement in student performance. This aligns with findings who reported improved safe injection practices among healthcare workers using the Plan-Do-Check-Act (PDCA) model, although their improvements were more modest and focused on system-based training in rural settings. Unlike our student-centered simulation approach targeting skill acquisition in a controlled academic environment, the PDCA model emphasized behavioral change in working professionals at a community health center. Additionally, found that geriatric simulation significantly enhanced nursing students' empathy and emotional intelligence, reinforcing the broader value of simulation-based training not only for technical proficiency but also for emotional and cognitive development. Taken together, these studies support the effectiveness of simulation-whether in pharmacological procedures or broader clinical contexts-as a powerful tool for enhancing both skill and sensitivity in healthcare education [15,16].

Our study revealed a statistically significant improvement in procedural skills related to intramuscular drug administration after mannequin-based simulation training. Notable gains were observed in areas such as hand hygiene, site identification and disinfection, patient communication, injection angle, medication delivery, and post-injection care. These improvements were confirmed by a paired t-test (p < 0.001) and Wilcoxon signed-rank test (p = 0.0156), highlighting the effectiveness of simulation-based learning in enhancing practical competence. In comparison, quality improvement project aimed at educating healthcare professionals on intramuscular injection techniques using PowerPoint presentations and pamphlets. While that study reported moderate gains, particularly in recognizing and utilizing the ventrogluteal and vastus lateralis sites (with a 36% and 27% increase, respectively), it did not significantly influence other aspects like Z-track use or aspiration techniques. Unlike Annutto's study, which targeted working professionals through passive education methods, our intervention actively engaged students in hands-on simulation, leading to more comprehensive skill acquisition. Although presented a high-tech, nonlinear analysis method for characterizing Parkinsonian tremors-unrelated in content-their approach reflects the growing integration of precision methods in clinical practice. Thus, compared to other training approaches, our simulation model provides a more immersive, statistically robust, and skill-centered strategy for improving injection techniques among medical trainees [17,18].

Our study demonstrated a statistically significant improvement in procedural skills related to subcutaneous drug administration following mannequin-based simulation training. Participants showed marked progress in essential competencies such as hand hygiene, syringe handling, site identification, angle control, injection technique, and post-injection care. The gains were confirmed by both the Wilcoxon signed-rank test (p = 0.0313) and the paired t-test (p = 0.00014), underscoring the effectiveness of simulation-based learning in enhancing practical proficiency. In contrast, the focused on safety-related issues and usability errors in disposable auto-injection devices. Their analysis cataloged 232 use errors across 38 qualified studies, identifying numerous design and handling challenges that compromise the effectiveness and safety of auto-injectors, particularly in emergency settings. While their study highlights the importance of minimizing user-related errors through improved device design and usability engineering, our findings emphasize the value of structured training in preventing similar errors by equipping healthcare learner's with hands-on experience and competence. Together, both studies point to complementary strategies-device refinement and user skill development-as essential for ensuring safety and efficacy in subcutaneous drug delivery [19].

CONCLUSION

Mannequin-based simulation was found to be an effective, engaging, and statistically beneficial teaching tool for pharmacology practical training among second-year MBBS students. It significantly improved procedural skills in administering IV, IM, and SC injections and was well-received in terms of student perception and confidence. The simulation environment offered a safe, reproducible, and realistic platform for practicing drug administration without compromising patient safety. The findings support the integration of simulation-based training into routine pharmacology education to enhance clinical competency and bridge the gap between theoretical knowledge and clinical application.

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