CLINICAL SIMULATION FOR PROCEDURAL EXPERTISE: STATE OF EDUCATION AND APPLICATION

K Kodikara[1]

Abstract

Procedural skills are a core component in the health care practice that extends across all medical practitioners, from novice trainees to specialists. Medical institutions have widely adopted simulation to develop the clinical and procedural skills of health profession students. This review evaluates the evidence regarding simulation-based training for developing procedural expertise among medical students and junior doctors. For this purpose, Google Scholar and MEDLINE/PubMed databases were searched for articles published on simulation-based procedural training between January 2000 and October 2023. Reviews or studies published in languages other than English and research that showed evidence on communication, critical thinking, teamwork, decision-making, and cognitive skills were excluded from the search. The focus was placed on clinical and psychomotor skills as this review intends to inform clinical skills teaching and research practice. The results reveal that simulation-based training has been utilized increasingly to train medical students and junior doctors in procedural skills. Varying levels of fidelity have been incorporated to train psychomotor skills about a multitude of common and rare procedures. The evidence supports the acquisition of knowledge and procedural skills via simulation. Evidence also supports the transfer of skills from the simulated environment to clinical practice and live patients. However, resource intensiveness has limited the implementation of this method of education in developing countries. When used consciously, simulation can complement clinical training to produce competent doctors capable of effective patient care.

Keywords: Competence, Procedures, Simulation

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[1] Department of Medical Education, University of Kelaniya

Email: k.kodikara@kln.ac.lk https://orcid.org/0000-0003-1546-8100

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Introduction

Acquisition of basic clinical and procedural skills is essential for medical students to practice as clinicians. Traditionally, knowledge, skills, and attitudes were taught or acquired by medical students at the bedside in the hospital setting during their clinical attachments (Cooke et al., 2006). The students were expected to perform basic procedures independently after observing the teachers performing procedures or participating in demonstrations performed by seniors or other healthcare professionals. This method of learning, which occurs in ward-based clinical attachments, follows the "see one, do one" approach (Dent & Harden, 2001). When training medical students to become medical professionals, bedside teaching is invaluable and important and, thus, should be an important aspect of their training (Kroenke et al., 1997; Ward et al., 1997). Despite the apparent merits of bedside teaching, this method of education is declining in medical institutions today, especially in the domain of procedural skills (LaCombe, 1997).

Practising invasive procedures on patients without proper training and observation imposes an ethical issue (Ziv et al., 2003). In addition, the quantity and quality of ward-based teaching, mainly for procedural skills, seems to have deteriorated mainly due to inadequate supervision by the clinical teachers (Van Der Hem-Stokroos et al., 2001). Although patients are willing to accept trainee involvement in nonprocedural care, they are usually reluctant to allow medical students to perform procedures on them (Graber et al., 2003). The rising emphasis on patient safety over medical students' learning and patients' right to trained care are contributory factors that discourage medical students from practicing on patients (Okuda et al., 2009). Therefore, the opportunity to develop basic procedural skills in the ward-based setting has become a challenge, which has led to wide variations in the competency of performing procedural skills among medical students (Van Der Hem-Stokroos et al., 2001). Such deficiency has led to reduced self-confidence mainly due to anxiety and fear of causing harm to patients (DuBoulay & Medway, 1999).

Several studies have shown that medical undergraduates were underexposed to and far from competent performing basic procedures upon graduation (Barr & Graffeo, 2016; Carr et al., 2012; Hannon, 2000). Studies conducted in America have shown that most medical students have not performed basic procedural skills such as venipuncture, intravenous catheter insertion, and arterial blood sampling during their clinical attachments (Wu et al., 2006, 2008). Nevertheless, medical students are expected to be proficient in practicing as clinicians upon graduation. Simulation training has been eventually integrated into medical curricula to bridge the gap in the education experience of medical undergraduates as an attempt to meet the expectations required of a graduating medical officer (Issenberg et al., 2005; Scalese et al., 2008).

Simulation is an instructional process replicating real-life patients or situations with artificial models for learning, feedback, and assessment (Gaba, 2004). Simulation creates a safe education environment that encourages experiential learning with trial and error, enabling students to practice without adverse outcomes (Gordon et al., 2001; Okuda et al., 2009; Pombo et al., 2017; Ziv et al., 2005). It employs various instructional approaches, including Payton's four-step approach (Krautter et al., 2011), widely used in teaching and learning procedural skills. Following each simulation session, the students are engaged in a debrief session which provides structured educational feedback, a unique feature in simulation-based medical education, which enables students to reflect on their performance (Issenberg et al., 2005; McGaghie et al., 2010; Wulf et al., 2010).

Deliberate practice, a cornerstone in simulation training, facilitates the acquisition of expertise in clinical procedures with repeated practice, which is often difficult in the hospital setting when learning from actual patients (Ericsson, 2004; Mcgaghie et al., 2011). The students undergo training in procedural skills in the clinical skills laboratories using manikins or part-task trainer models before interacting with actual patients (Bradley & Postlethwaite, 2003; Dehmer et al., 2013; Scalese et al., 2008) well as with students (Nikendei et al., 2005) or using standardized patients (Barrows, 1993).

Numerous studies have shown the effectiveness of simulation for procedural skills acquisition. However, critical reviews of simulation for procedural skills training have been rarely conducted in the last decade (Ayaz & Ismail, 2022). This review aims to collate and summarize the use of clinical simulation and its effectiveness for procedural training among students of health professions.

Methodology

A broad electronic search of the Google Scholar and MEDLINE/ PubMed databases was performed to extract relevant studies published between January 2000 and October 2023. The search strategy used both medical MeSH terms and free-text words. The search was performed using the following terms: 'Simulation for procedural training in the undergraduate medical curriculum', 'Competency after procedural simulation in the undergraduate medical curriculum', and 'Procedural simulation application in the medical curriculum.' Duplicates were eliminated by going through the abstracts. Reviews or studies published in languages other than English and research that showed evidence on communication, critical thinking, teamwork, decision-making, and cognitive skills were excluded from the search. The focus was placed on clinical and psychomotor skills as this review intends to inform clinical skills teaching and research practice. The final selected studies were then read in detail. Based on the literature review, the following important content was extracted.

Results

Types of simulators

Several types of simulators are used in present-day medical education to deliver teaching/ learning experiences to learners. Simulator types are categorized commonly according to the degree of sophistication of the simulator (Bradley & Postlethwaite, 2003). The most basic type of simulator is the part-task trainer. A part-task trainer is an object that replicates a segment of a complete process. These can be a limb, body part, or structure (intravenous venepuncture arm, endoscopy trainers). These are usually used to learn technical, procedural, or psychomotor skills, such as venepuncture, ophthalmoscopy, and catheterization. Not all part-task trainers are of low-technology. Harvey and the Simulator-K are high-fidelity cardiovascular systems. These help learners recognize common cardiac auscultatory findings (Gordon et al., 1980; Takashina et al., 1997). These simulators also aid in developing basic and sophisticated surgical techniques.

Learners use part-task trainers to improve the performance of an isolated task through repetitive practice (Bradley, 2006). Some of these simulators can provide feedback to the learner via visual, auditory, or printed form on the quality of their performance (e.g. feedback on the adequacy of depth of chest compressions). They can be used in combination to enhance the learning experience as well. Mid-range simulators primarily consist of whole or half-bodied mannequins. These simulators can demonstrate a few functions but are not able to produce a complete physiological response.

High-fidelity simulators use advanced technology that usually combines a full-body mannequin with sophisticated computer controls that can be manipulated to provide various physiological parameter outputs (Issenberg et al., 2005). These outputs can be physical (e.g. a pulse rate or pupillary movements) or electrical (presented as monitor readouts) that can be automatically pre-programmed to run a specific scenario by a physiological and pharmacological model incorporated within the software or can be controlled by the instructor according to learner's actions. (Bradley, 2006) Most mannequins have an artificial airway and can have appendages such as catheters, chest tubes, or nasogastric tubes inserted. The METIman and Medsim were early high-fidelity simulators that have evolved into highly sophisticated mannequins available today.

The unpredictability of human behaviour within social contexts in which humans operate can lead to unrealistic simulations when mannequins are solely used. Therefore, educators use volunteer, simulated (standardized) patients (Kneebone et al., 2002). Simulated patients (SP) are individuals playing the roles of patients. They may be actors or volunteers who may allow procedures to be performed on them (e.g. Body Mass Index (BMI) measurement, intrusive examinations). Moreover, "Expert" patients can also be used for this purpose. They are individuals with a specific condition or illness who could either recount to students their stories or influence the provision of education (Griffiths et al., 2007). Another approach is the instructor simulating a patient by disguising themselves (Reid-Searl et al., 2011).

'Hybrid simulators', also known as 'patient-focused simulation', describe a simulator (usually a part-task trainer) coupled with a SP. This combination enhances the realistic nature of the learner-scenario interaction and enables the learning and teaching of both technical and communication skills (Nestel & Kneebone, 2010). Another type of simulator is computer simulation, such as virtual reality (VR) and haptic systems (Bradley, 2006). Virtual reality refers to the recreation of environments or objects as a complex, computer-generated image. Haptic systems refer to the replication of the kinaesthetic and tactile perception. Often, VR and haptic systems are combined with a part-task trainer. These systems aid in training vascular access, endoscopy, and laparoscopic surgical techniques. Kneebone describes a subcategorization of computer-based VR simulators: precision placement (e.g. vascular access), simple manipulation (e.g. sigmoidoscopy), and complex manipulation (e.g. anastomosis) (Kneebone, 2003). He also describes a higher level of integrated procedures, which are in keeping with fully integrated high-fidelity simulators.

The term 'fidelity' is used in simulation to describe some aspect of the reality of the experience. Fidelity can be defined as the extent to which the appearance and behaviour of the simulator⁄simulation match the appearance and behaviour of the simulated system (Farmer et al., 2017). Evidence shows that increasing the fidelity of the training device will produce only minor improvements in performance beyond a certain level of fidelity over a more straightforward device (Kodikara et al., 2020; Maran & Glavin, 2003).

Use of simulation for procedural training

Procedural skills are a core component in health care practice, spanning all medical practitioners, from novice to specialist (Kneebone et al., 2006). Part-task training models are used increasingly to aid the acquisition of procedural skills. These models represent a part of the body, often comprising a limb or a body structure, e.g., plastic arms for venepuncture or suturing, female pelvis model (Bradley, 2006; Scalese et al., 2008). These are used to train specific procedural skills such as venepuncture and pelvic examination. This allows learners to focus on an isolated task and achieve expertise with repeated practice. Part-task training models can be coupled with simulated patients to provide a realistic clinical scenario where communication skills paired with technical competence are learned (Kneebone et al., 2002).

A study conducted across several medical institutions in 2016 revealed that most medical students were underexposed to essential bedside procedures (Barr & Graffeo, 2016). Furthermore, the study revealed that the students feel uncomfortable performing such procedures. The study revealed that lower confidence and competence in performing clinical procedures have worsened over the last 25 years of medical education. They suggest simulation training in procedural skills as a valuable educational tool to familiarize students with essential bedside procedures to mitigate the problem of incompetence and low self-confidence. Medical students with simulation training were found to be more comfortable with and willing to perform procedures independently than those trained without simulation (Sanchez et al., 2006). In addition, Graber et al. (2003) demonstrated that patients are more willing to allow simulator-trained medical students to perform procedures on them.

To overcome deficiencies in clinical experiences and practical expertise in clinical and procedural skills of medical undergraduates, an Austrian medical school has implemented an innovative course on teaching basic clinical and procedural skills to its first-year medical students (Mileder et al., 2014). This course was carried out over one year from 2011-2013, with 418 students completing it. In this study, students highly appreciated the course and the opportunity to receive practical skills training and hands-on experience using medical simulation during the preclinical years.

McGaghie et al. (2011) performed a meta-analysis on clinical simulation research over 20 years from 1990-2010. This study evaluated evidence on the effectiveness of simulation training with deliberate practice versus traditional clinical education about clinical procedures (Mcgaghie et al., 2011). Of the 14 studies subjected to this review, six studies have shown improvement in laparoscopic skills, and two studies demonstrated improvement in cardiac auscultation skills, identification, and interpretation of heart sounds and murmurs among medical undergraduates and residents. Four studies subjected to this review have demonstrated improvement in performing invasive procedures with simulation-based learning and deliberate practice. They conclude that SBME is superior to traditional clinical training in the acquisition of procedural skills.

In a study that evaluated the effectiveness of simulation-based learning on procedural skills, McKay and others conducted a simulation training on four procedural skills among second and third-year medical students: Intubation, lumbar puncture, arterial line placement, and central line insertion (Toy et al., 2017). Twenty-four students were trained by anesthesiology residents in six 4-hour sessions, and the data were collected using multiple choice questions and performance checklists. Although the study showed significant improvement in knowledge, skills, and self-assessed confidence, the investigators concluded that focusing on four procedures in one training session limited effective learning and assessment time. They recommended increasing the study sample and conducting real-time skills assessment.

Reed et al. (2016) hypothesized that simulation-based learning improves knowledge acquisition and procedural skill performance. Their study was conducted among 135 medical students who were in their emergency medicine attachment (Reed et al., 2016). Pre-tests and post-tests following the simulation sessions were carried out for six core procedural and clinical skills: laceration repair, chest compressions, bag-valve-mask ventilation, defibrillator management, code-leadership, and ultrasound-guided peripheral intravenous placement. The study found that a significant number of students achieved pass marks and showed a significant improvement on the assessments following simulation-based learning. They concluded that simulation-based learning is effective in acquiring emergency medicine-related procedural and clinical skills.

A review article conducted in 2007 by Lynagh et al. evaluated 44 randomized controlled trials that evaluated simulation training in procedural skills. They demonstrated that most studies (70%) reported that simulation training significantly improved the performance of procedural skills compared with standard clinical training when assessed on simulators. He recommends further study to assess the transferability of acquired skills to clinical practice (Lynagh et al., 2007).

In using simulation as an assessment tool, Hallikainen and others observed that the familiarity of the simulator trained students to the simulated environment as a limitation in using simulation as an assessment tool for procedural skills (Hallikainen et al., 2009). A study conducted among final-year medical students at a Canadian medical school found that students and educators highly appreciated using simulation technology for learning and teaching purposes. However, they were not very satisfied with using simulation technology for evaluation (Morgan & Cleave-Hogg, 2000). Identifying these limitations in using simulation for evaluation has led to development of the integrated procedural performance instrument (IPPI). This intervention makes the evaluation environment more realistic and clinically oriented. It enables assessment of not only the technicality of the procedure but also the student's overall performance in performing the procedure as he would in the actual clinical context (Kneebone et al., 2006).

Effectiveness of simulation for acquiring procedural expertise

Simulation has already been incorporated internationally into undergraduate medical curricula (Bradley, 2006). Educators have predicted that the use of simulation will increase with falling opportunities for quality clinical placements (Maran & Glavin, 2003). Given the resource intensiveness of simulation-based medical education (O'Flynn & Shorten, 2009), it is vital to establish whether SBME is an effective educational strategy, and thus, it becomes incumbent on medical educators to demonstrate the effectiveness of simulation (Gaba, 2007; McGaghie et al., 2010; Okuda et al., 2009).

Simulation-based research conducted over decades is ripe with evidence supporting improved educator and learner satisfaction (Bradley, 2006), learner knowledge and confidence (Battaglia et al., 2021; Laschinger et al., 2008), and competence when assessed on simulators (Hale et al., 2021; Morgan & Cleave-Hogg, 2000). Although most studies support the use of simulation for improved knowledge and skill, only a few studies have shown the effectiveness of transferring knowledge and skill gained in simulation training into clinical practice (Hill et al., 2011). Furthermore, the use of simulation as an assessment tool is increasingly questioned as to whether the demonstrated performance in an artificial environment would apply to an authentic clinical setting (Hallikainen et al., 2009). Demonstrating skill transfer has gained importance with the recent emphasis on investigating translational research (Lynagh et al., 2007; McGaghie et al., 2010). However, there is a dearth of evidence on the post-simulation transfer of skills for medical undergraduates as a discreet population (Cox et al., 2015; McGaghie et al., 2014; Singh et al., 2014; Vanderbilt et al., 2015).

In a systematic medical skills laboratory training review, Lynagh *et al.* (2007) report that 44 studies demonstrated skill improvement with simulation-based teaching. They report that only 20 studies showed skill performance with simulation-based training translated to the clinical environment. However, they further mentioned that eight of the 20 studies used animal models to demonstrate the transfer of acquired skills. The other 12 studies have used actual patients to demonstrate skill transfer to clinical practice with positive results. However, these studies on endoscopic and laparoscopic surgical skills had been conducted among postgraduate trainees. A systematic review and meta-analysis of 39 RCTs by Singh et al. (2014) reported that simulation-based education in gastrointestinal endoscopy is associated with improved performance in clinical settings and improved patient outcomes. Vanderbilt et al. (2015) reported that simulation training resulted in benefits at the operating theatre in minimizing procedural errors and improving overall patient safety. For this purpose, they reviewed 21 RCTs in their systematic review. Cox et al. (2015) conducted a systematic review of 12 studies that evaluated the transfer of skills to clinical practice following simulation-based procedural training. They concluded that simulation-based procedural training allowed the transfer of learning to practice. McGaghie et al. (2014) reported that simulation-based mastery learning produces downstream translational outcomes. This critical review evaluated the outcomes of 23 studies.

The study designs adopted for investigating the transfer of skills to clinical practice ranged from randomized control trials (RCT) (Jensen et al., 2014; Kodikara et al., 2023a; Lee et al., 2015) and pre and post-test studies (Barsuk et al., 2016; Cannon et al., 2014; Kodikara et al., 2023b). reported a significant improvement in skill performance. They demonstrated evidence of skill transfer to clinical practice from the simulated environment in training on intravenous cannulation among medical students. Jensen et al. (2014) conducted an RCT among 54 resident physicians. When comparing the real-life performance of simulator-trained vs non-simulator residents in cardiac angiography, they reported no significant improvement in the simulator-trained group. However, Cannon et al. (2014) reported significant improvement in simulator-trained orthopaedic residents performing diagnostic knee arthroscopy on a live patient. This was a blinded RCT that compared simulation-based training with regular institution-specific training. Kodikara et al. (2023a) conducted an RCT that compared simulator-trained medical students' performance with bedside venipuncture training. They reported a significant improvement in skills in the simulator-trained group.

Lee et al. (2015) conducted a pre-and post-test study on cardiovascular system examinations among 20 medical students. They compared the simulator-trained group with the clerkship-trained group. They concluded that the simulator-trained group could transfer the skills to an actual patient. Barsuk et al. (2016) compared simulator training with no training in thoracentesis among internal medicine residents. They concluded that the procedure was performed more and fewer referrals were made by the simulator-trained group when compared with the control group. Kodikara et al. (2023b) conducted a pre-and-post study on venipuncture among medical students. They concluded that students were able to demonstrate skills acquisition and transfer the skills learned to practice.

Measures of procedural competence

Training in clinical procedural skills is a fundamental component of medical curricula. Medical students are required to achieve competency in a range of skills by graduation to enable them to work safely and effectively in dynamic and unpredictable clinical environments (Frank et al., 2010; McGaghie, 2015). Both subjective and objective measures have been used in the literature to measure procedural competence among medical students.

Self-perception is the reported self-efficacy in performing a task (Bandura, 1997). The self-assessed competency refers to the perceived ability to perform clinical practical skills (Katowa-Mukwato & Banda, 2016), while objectively measured competence is the examiner-observed behaviour or practice of the learner. Determining the competency level of learners during the program and, more importantly, at the point of graduation is critical, as acquired competencies are a central indicator of the quality of the curriculum (Barbosa et al., 2011). Procedural competency of medical students has been investigated with both subjective and objective measures excessively in Europe and North America (Coberly & Goldenhar, 2007), and to some extent in Asia (Lai et al., 2009), and Africa (Katowa-Mukwato & Banda, 2016).

Discussion

Ensuring learners are prepared for clinical practice upon graduation is a concern shared by all healthcare professional educators. Students should be well prepared for clinical practice to apply the knowledge and skills they have learned for safe patient care. Learning in clinical settings has become challenging for students due to the deteriorating quantity and quality of ward-based teaching skills, inadequate supervision by clinical teachers, frequent assignment of students to routine activities of limited educational value, and increasing student numbers (Gisondi et al., 2018). Simulation has been identified as an aid in preparing students for clinical practice (Motola et al., 2013) and is incorporated into undergraduate medical education for this purpose.

This review identified the use of simulation for procedural training, specifically in terms of fidelity, effectiveness, and developing procedural expertise. However, clinical educators must be cognizant of the resource intensiveness of simulation-based learning that requires time, equipment, people, and space (Lapkin & Levett-Jones, 2011).

A low-fidelity mannequin is adequate for training on essential life support. It allows the distribution of multiple mannequins among more learners, which is a cost-effective method. However, for training the same, providing a high-fidelity mannequin for each student would be unnecessarily costly and lead to no higher learning outcomes. Complex training aids are not required where novice learners training basic skills of a task. However, when developing fine motor skills, the simulator needs to reproduce the actual situation accurately to avoid a negative transfer (Gagne, 1954). Therefore, at all levels of proficiency, different genres of simulators can be combined to increase fidelity and enable the achievement of better learning outcomes, which will overcome any resource limitations, especially in developing countries where this method of education is still not well established.

The goal of any teaching and learning activity is knowledge/skill acquisition. Therefore, it is unsurprising that most simulation-based research focuses on this area. Knowledge and skills were usually evaluated together as simulation demands both spheres of learning. Studies that evaluated improved skills performance post-simulation used subjective and objective measures. However, the degree of correlation between self-assessed and objectively measured competency is inconclusive (Barnsley et al., 2004; Lai & Teng, 2011; Morgan & Cleave-Hogg, 2002). While some found the correlation between self-assessed and objective measurements moderate (Coberly & Goldenhar, 2007; Lai & Teng, 2011), others report a significant correlation (Hicks et al., 2000). This inconsistency between self-assessed and objective measurements is possibly due to the fundamental cognitive limitation in the ability of humans to know themselves as others see them (Eva & Regehr, 2005). However, Eva and Regehr proffer two important functions of self-assessments: 1) a mechanism for identifying one's weaknesses and 2) a mechanism for identifying one's strengths (Eva & Regehr, 2005). Identifying weaknesses and strengths could improve one's persistence to achieve goals (Bandura, 1997). Thus, self-assessed procedural competency can be used promisingly and methodically in improving one's actual competency.

Few studies have investigated the transfer of procedural skills acquired through simulation-based training. For medical educationists, exploring the transfer of skills means observing students' performance on patients in the clinical environment, which is highly challenging (Arthur Jr et al., 2003). Consequently, existing literature on the transfer of learning from simulation to clinical practice is scarce (Laschinger et al., 2008). Most of such studies have observed the performance of endoscopic or laparoscopic surgical skills compared to standard or no training (Lynagh et al., 2007). McGaghie et al. (2011) showed that SBME with "deliberate practice" is superior to traditional clinical training in the acquisition of several procedural skills, including laparoscopic surgery skills, advanced cardiac life support, cardiac auscultation skills, hemodialysis catheter and central venous catheter insertion skills and thoracentesis skills (Mcgaghie et al., 2011). The recent RTCs demonstrated that simulation-based training helps acquire even basic procedural skills such as venipuncture and promotes the self-confidence of learners in performing procedures. The evidence supports that skills acquired through simulation-based training successfully transfer from a simulated setting into clinical practice.

Simulation-based procedural training has thus become a popular and effective method of achieving expertise. It utilizes “active” teaching techniques and ensures competency-based education (Issenberg et al., 2005). It has enhanced learner competence and expertise (Bamford et al., 2018; Greif et al., 2010; Hale et al., 2021; Hayden et al., 2014). Due to these findings, evidence supports the introduction of SBPT to students before clerkships (Battaglia et al., 2021; Omori et al., 2005) to better prepare them to learn in the clinical setting (Battaglia et al., 2021; Remmen et al., 2001).

Conclusion

The current review explores simulation-based education in developing procedural expertise among students of health professions. Evidence supports the use of a range of simulators of varying fidelity for knowledge and skills acquisition through simulation-based training. Consequently, simulation is widely and increasingly used in medical education to develop clinical and procedural expertise. However, the resource intensiveness of simulation-based teaching and learning has been identified as a major hurdle in implementing simulation-based education, especially in resource-poor settings. It is vital to weigh the risks and benefits to make informed judgments in utilizing this promising method of education.

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