Simulation in surgical education: a brief review

Lama Islem A. Basunbul¹, Najd Muhammed S. Aljuaid¹, Shahad Amro O. Almughamisi², Leena H. Moshref⁴, Rana H. Moshref¹*, Nadim Malibary¹, Abdulaziz M. Saleem¹

ABSTRACT
In medical education, the ultimate goal of training is to improve clinical outcomes and patient comfort. Surgical education is changing dramatically, and obtaining surgical competency is a perplexing process that necessitates acquiring a high degree of knowledge and surgical skills by learners. The purpose of this review is to describe the various types of simulation systems used in surgical education. The online database PubMed was used to perform a literature search for publications without any date or language restrictions. We used a combination of relevant search terms “(Simulation) OR (Simulator) OR (Mannequin) OR (Manikins) OR (Bench models) OR (Virtual Reality Simulations) AND (Surgery) OR (Surgical Education) OR (Surgical training)” We independently identified publications and systematically screened titles, abstracts, and full texts of the collected publications. Finally, 30 articles were selected for data extraction. Surgical simulations were classified as low or high fidelity based on their resemblance to the real world. However, the fidelity level should be appropriate to the trainee’s training stage. The current review found the need for simulation to be increasingly significant in surgical education in educating trainees in technical and non-technical skills. One of the most significant advantages is that it allows the student to practice a surgical technique before doing it on a patient.

Keywords: Simulation, medical education, fidelity, surgery.

Introduction
In medical education, the ultimate goal of training is to improve clinical outcomes and patient comfort. Surgical education is changing dramatically, and obtaining surgical competency is a perplexing process that necessitates acquiring a high degree of knowledge, judgment, professionalism, and surgical skills by learners. When looking at surgical education trends, it’s clear that the faculty have been pushed to change or adjust how they teach technical skills [1]. In surgical training, simulation can include both operational and non-operative procedures and multi-specialty and multi-disciplinary scenarios [2]. For decades, surgical training was based on the apprenticeship model, in which students learned by seeing and assisting the trainer or teacher. In most cases, no actual patient care was provided in hospitals [3]. Simulator training was done on cadavers, benches, and animal models. Technological breakthroughs have cleared the path for the use of virtual reality simulation (VRS) in surgical training as a result of rapid and efficient changes in surgical education.

A surgical training program consists of a series of proctored events that teach trainees how to conduct treatment or surgery and how to care for a surgical patient. The simulation laboratory is the appropriate area to improve trainees’ or residents’ skills by allowing them to practice operations in a safe, controlled, and calm environment. Simulation is a recreational simulation of a real-life event, either partially or entirely, that is as close to reality as possible, providing learners with a safe setting for practice and error, with opportunity for feedback and assessment [4]. Alternative approaches to achieving surgical skills within the constraints that surgery residents face during their training, such as...
Simulation in surgical education

restricted clinical exposure and work hour restrictions, are also possible. Residents should also be taught in crisis resource management and a team approach for preventing and minimizing medical crises, and these skills can be exercised away from the emergency setup in a stimulatory laboratory [5]. However, before being employed in high-stakes examinations, the simulation methods must exhibit good validity and reliability. The purpose of this review is to describe the various types of simulation systems used in surgical education, as well as their uses, benefits, and limits.

Literature Search

The online database PubMed was used to perform a literature search for publications without any date or language restrictions. We used a combination of relevant search terms “(Simulation) OR (Simulator) OR (Mannequin) OR (Manikins) OR (Bench models) OR (Virtual Reality Simulations) AND (Surgery) OR (Surgical Education) OR (Surgical training) OR (Clinical training)”. We independently identified publications and systematically screened titles, abstracts, and full texts of the collected publications. Finally, 30 articles were selected for data extraction.

Results

Categories

Surgical simulations are classified as low or high fidelity based on their resemblance to the real world [6]. Low-fidelity models, also known as table-top simulators, on the other hand, are typically used for the repetitive simulation of a specific skill that can help trainees master individual techniques because they are less expensive than high-fidelity models and have a lesser degree of realism; such as, suturing techniques and hand-eye coordination. High-fidelity models are useful for closely simulating the operating room, but they are often expensive and time-consuming to manage. However, the fidelity level should be appropriate to the trainee’s training stage and the type of tasks (technical or non-technical skills) [7,8].

Bench models

Bench models, tower trainers, manikins, live animals, human cadavers, human performance simulators, and virtual reality are simulation tools used in surgical education, depending on the task and stage of training.

Bench models have two types: low and high-fidelity models. Low-fidelity bench models use stand-alone synthetic simulators to practice basic surgical skills like knot-tying and suturing. They are among the cheapest and simplest models used in surgical education [1,3]. Simultaneously, high-fidelity bench models combine synthetic and animal parts with training complexes and advanced surgical skills like joint replacement, fracture fixation, aneurysm repair, and minimally invasive surgeries such as laparoscopic surgery [9]. The McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) is a well-established training model that helps to carry out standardized tasks with good speed and precision [10]. This system enables the training surgeon to demonstrate the procedure in a trainer box (closed environment) equipped with a laparoscopic optical system (cameras) so that trainees can observe the movements.

Cutting, peg transfer, suturing, and placing a ligating loop are some of the basic laparoscopic skills taught with MISTELS [11]. Bench-top and laparoscopic box simulators have been shown in studies to improve surgical skills and develop hand dexterity and hand-eye coordination required for surgery [12,13].

Manikins

Manikins or Mannequins are used as simulation models in surgical training, with the concept of segmented or whole-body patient simulators that safely allow the trainee to learn and practice. Basic surgical skills depend on the level of realism. Low-fidelity manikins are utilized to practice CPR or IV-arm skills on a segmented clinical task trainer, whereas mid-fidelity manikins are frequently full-body virtual people [14]. The American Heart Association’s Advanced Cardiac Life Support program, which is popular among medical professionals, uses manikins to educate how to recognize and treat cardiac and respiratory arrests, as well as how to manage arrhythmias [15]. Similarly, manikins are used in the Advanced Trauma Life Support training offered by the American College of Surgeons to teach early recognition of shock and resuscitation [16]. On manikins, trainees can practice chest tube installation or cricothyrotomy, which is commonly used in surgical teaching. Carotid endarterectomy, open aortic aneurysm, and other vascular surgical procedures are taught [17,18].

Cadavers

The mainstay in operative surgical education is cadavers. Cadavers have been used to educate human anatomy and surgery for centuries. These models give extreme high-fidelity surgical anatomy simulation as close to in vivo as feasible, an approximation to living tissue, and complicated three-dimensional neurovascular interconnections that are impossible to recreate in synthetic models [19]. The practice of flap utilization was used in cadavers, in addition to laparoscopic and minimally invasive surgeries. Human cadavers, on the other hand, are difficult to come by and extremely expensive. They also need to be maintained regularly, require a unique storage configuration, and aren’t reusable for some procedures. Furthermore, embalmed cadavers have low tissue compliance, making them unsuitable for some intricate and difficult procedures [12,19]. According to Sheckter et al., practicing cadaveric models boosted the number of surgeons who participated in plastic surgery residency programs [20].
Live animals

Because human cadavers have some limitations, live animals have been used to simulate certain surgical procedures because they share many similarities with human surgeries. The animal model has several advantages, including simulating tissue handling and hemostasis with high fidelity [21]. The animals are anesthetized during the procedures, which allows residents to practice technical skills and non-technical abilities, for instance team work, communicating in harmony, situation awareness, decision making, and leadership, which will aid in learning the avoidance and management of complications. Endoscopic and laparoscopic surgeries and other procedures such as cholecystectomy, coronary bypass, and endoscopic submucosal dissection have been practiced using in vivo porcine and canine models [22]. One of the major constraints in using these models is the ethical concerns raised by certain organizations regarding using animal bodies for simulation, as they consider animal vivisection to be inhumane.

Virtual reality simulations (VRS)

Because this VR simulator provides digital recreations of real-life events, technical breakthroughs have cleared the road for using augmented reality in surgical education. Based on its level of realism and tactile capabilities, each reality system is unique [23]. Modern VR simulators provide high-fidelity simulation and aid in the accurate capturing of minute anatomical details. The majority of today’s VR simulations are intended for laparoscopic and endoscopic procedures. NeuroTouch, Laparoscopy Simulator (LapSim), and Lap Mentor are among the high-fidelity VR systems already in use, and low-fidelity VR systems like Minimally Invasive Surgical Trainer - VR are also being used to teach some basic surgical skills [24]. The SEP-Robot (SimSurgery, Oslo, Norway), Robotic Surgery Simulator, dV-Trainer (MIMIC Technologies, Seattle, WA), and da Vinci Skills Simulator (Intuitive Surgical, Sunnyvale, CA) [25] are the four types of simulators in this system. The da Vinci surgical system, which is a robot-assisted laparoscopic surgery device, has been widely employed in teaching laparoscopy and endovascular procedures. These low-fidelity VR simulators are frequently used to teach inexperienced learners specific surgical skills. Another appealing feature of VRS is that it provides real-time haptic feedback on the user’s performance [24]. Large expenditure, paucity of evaluation, and poor realism in few models are some of the disadvantages of VR simulators.

A new addition to these VR models is the “Patient-specific VR simulator” that allows simulation using saved imaging information of patients to practice procedures preoperatively. These types of VRS eradicate the chance of inaccuracy and grant real-time communication of the procedure, as there is high patient-specific anatomic accuracy [24]. It has been widely used in hepatectomies, pancreatectomies, renal surgery, and hand surgery procedures. Another system called virtual interactive presence and augmented reality has been recently used by surgeons to collaborate remotely [26]. The surgeon’s observed territory is transformed to simulation in this system, which is then projected remotely to another surgeon in another place utilizing high-resolution cameras and faster internet access [24,26].

3D rapid prototyping

These simulation methods employ medical imaging techniques such as computed tomography and magnetic resonance to generate 3D miniature to patient-specific, allowing surgeons to practice the steps of the procedure before they are performed. With the use of 3D printers, fused filament deposits, stereolithography, and scintigraphy, some recently developed typographers can yield similar tissue types that can accurately and realistically replicate the anatomical structures of real patients [27]. These models have been used in specialties such as cardiac surgery and neurosurgery, allowing for the planning of complex surgical procedures.

Evidence suggests that using 3D printing preoperatively helps surgeons feel more confident during surgery [28].

Surgical Boot Camps

Surgical Boot Camps are simulation-based training programs that have been shown to help acquire and develop the technical and non-technical skills needed for surgical competency. Due to the shorter length of surgical postings during their internships, most students accepted for surgical residency programs are unprepared to conduct numerous fundamental surgical operations. These boot camps in medical education could boost a trainee’s confidence and expertise before entering surgical residency programs [29].

Discussion

In surgical education, simulation-based training offers a similar experience that shortens the learning curve and improves patient experiences. Trainees are required to master the surgical abilities required to perform effectively at their level after incorporating competency-based medical education into the curriculum. Entrustable professional activities have been established in this regard to assess the performance of trainees who have been entrusted to perform autonomously, either individually or collectively [30]. In this paradigm shift, simulation and simulation centers play a critical role. Many surgical training programs employ simulation techniques, and valid simulators must be incorporated into structured surgical training curriculum. The use of simulation tools in training programs should be maximized. These training strategies can only increase essential surgical
skills among trainees if used consistently and assessed properly. Future research on the advantages of simulation in surgical training should demonstrate its purpose and effectiveness while adhering to recognized validity criteria.

**Conclusion**

Simulation is becoming increasingly significant in surgical education to educate trainees on technical and non-technical skills. New equipment and techniques have been developed due to technological advancements, and they must be taught to trainees in a safe environment where patient safety issues may be addressed. One of the most significant advantages of the simulation is that it allows the student to practice a surgical technique before doing it on a patient. As simulation techniques progress and become more well known, it would not be unreasonable to use them to assess a surgeon’s competence or to permit trainees to perform a certain procedure.

**List of Abbreviations**

- MISTELS McGill Inanimate System for Training and Evaluation of Laparoscopic Skills
- VRS Virtual reality simulations

**Conflict of interest**

The authors declare that there is no conflict of interest regarding the publication of this article.

**Funding**

None.

**Consent to participate**

Not applicable.

**Ethical approval**

Not applicable.

**Author details**

1. General Surgery, King Abdulaziz University Hospital, Jeddah, Saudi Arabia

**References**


