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The Role and Validity of Surgical Simulation

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In the last three decades, simulation has become a key tool in the training of doctors and the maintenance of patient safety. Simulation offers an immersive, realistic way of learning technical skills. Recent changes to the training schemes in many surgical specialities mean that the hours spent working between senior house officer and consultant have been reduced. This, combined with other pressures (such as reduced operating hours), means that surgery has moved away from its traditional apprenticeship model and toward a competency-based one. Simulation can be a standardized and safe method for training and assessing surgeons. Use of simulation for training has become significant alongside the development of laparoscopic techniques, and evidence suggests that skills obtained in simulation are applicable in real clinical scenarios. Simulation allows trainees to make mistakes, to ask the "what if?" questions, and to learn and reflect on such situations without risking patient safety. Virtual reality simulators have been used to allow experts to plan complicated operations and assess perioperative risks. Most recently, fully immersive simulations, such as those with whole theater teams involved, and patient-centered simulations allow development of other key skills aside from purely technical ones. Use of simulation in isolation from traditional teaching methods will furnish the surgeon in training with skills, but the best time and place to use such skills comes only with experience. In this article we examine the role of simulation in surgical training and its impact in the context of reduced training time.

Key words: Simulation – Surgical education – Surgical training – Laparoscopic surgery

Simulation is defined as "a technique to replace or amplify real experiences with guided experiences, often immersive in nature, that evoke or replicate substantial aspects of the real world in a fully interactive manner."[1] The past three decades have seen a rising interest in the use of simulation for the purposes of training doctors, quality of care, and patient safety. Simulation was first described when leaf and clay models were used to simulate the very first recorded operation, a forehead flap

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nasal reconstruction in ancient India in 600 BC.[2] In modern times, early experience in simulation came from the Resusci Annie, a training mannequin for teaching basic life support that was introduced in 1960.[3]

Today there are laparoscopic surgery simulators with haptic or tactile feedback, wet-lab courses involving live animals in laparoscopic or microsurgery, and virtual reality computer programs addressing a widening range of surgical and interventional procedures.[4–9] Even virtual hospitals have been created with simulation-based learning in mind, such as the Medical Simulation Centre at Loma Linda University in California.[10,11] Much of the technologic development in simulation has come from computer gaming, and practical usage has been exploited greatly in aviation through flight simulators, which train pilots to fly.[12]

The Rising Importance of Simulation

The past century has seen a growth in our understanding of the structure and function of the human body in health and disease. This has been coupled with advances in diagnostics and imaging as well as treatments to cure and manage disease. Such a rapidly growing knowledge base has necessitated the embrace of knowledge management, new technologies, and new pedagogic approaches.[13] This trend has been coupled with a desire to reduce the number of hours worked by surgeons both in Europe and the United States. [14]

In the United Kingdom, following Calmanization (the combination of many registrar grades into one grade—the Specialist Registrar), modernizing medical careers, and the European Working Time Directive, a trainee's hours have theoretically reduced from approximately 30,000 to 6000 working hours between becoming a Senior House Officer and becoming a Consultant.[15–18] For a craft specialty like surgery—that is, one highly reliant on developing fine motor skills, such as dexterity and coordination—this reduction in "hands-on time" could have significant ramifications for training.[19]

Such changes have heralded a transition in surgical training from an apprenticeship model, where the learner imitates the actions of a skilled mentor and which relies on subjective evaluations, to a more objective and competency-based attitude that requires the trainee to be more "hands-on" in his or her own approach to training.[20,21] Other drivers for change include the rise of evidence-based medicine, medical error statistics, rising student numbers, bed occupancy and theater time pressures, decreasing patient availability, changing patient attitudes, rising patient and public expectations, and wider societal changes.[22–24]

Lessons From Laparoscopic Surgery

The first reported laparoscopic cholecystectomy was done by Philippe Mouret in France in 1987.[25] Within 5 years it was established as a feasible alternative to the open approach.[26] However, doubts were soon raised about its safety and the credentials of those performing the procedure.[27] Professional societies began to emphasize training both inside and outside the operating theater and to stipulate minimum requirements for those performing laparoscopic surgery.[28,29] Skills courses were introduced to teach basic psychomotor skills and to get people accustomed to the fulcrum effect, viewing two-dimensional images on a screen 2 meters away with limited tactile feedback. Gradually, laparoscopic cholecystectomy became safer and a viable alternative to the open technique.[30] Today, laparoscopic surgery is considered "safe" and is more widely used than the open technique.[31] The debate has now moved on to the number of ports one should use.[32]

Advantages of Simulation and Integration With Learning Theories

Simulators can provide a safe and standardized method for training in surgery without the risks that come with operating on real patients. Such experiences can be realistic, highly engaging, and immersive, such that users forget they are in a simulation.[33] Here, the acquisition of competency in procedural skills occurs hand in hand with team building and communication skills within an educationally focused environment.[33,34]

Learners can refresh themselves and gain confidence regarding infrequent or rare circumstances, intimate examinations, and risky procedures like arterial cannulation; iteratively practice protocols and drills; enhance the automaticity of emergency procedures; and ultimately develop professional and clinical competencies.[1] The recent landing of a plane in the Hudson River in New York serves as a powerful example of the benefit gained from simulation. It was made easier by the fact that US Airways pilots do frequent drills of water landings in a flight simulator.[35]

Dynamic variation during emergency scenarios can be used to test the integration of knowledge (*e.g.*, sudden loss of airway scenarios in a polytrauma patient in the Acute Trauma Life Support course moulage).[36] From an ethical point of view, Ziv *et al*[37] have argued that doctors have a moral imperative to ensure patients get the highest quality of care and should not be treated by those who have not shown that they can perform the task safely and reliably. Such thinking will inevitably lead to its increased use in training and examination.

What about surgical simulators?

Simulation also helps to enhance psychomotor skills, hand-eye coordination, and ambidextrous surgery, especially important for endoscopic surgery.[38] Seymour *et al*[38] assessed the skills acquisition of 16 trainees randomized to either traditional training or a laparoscopic simulator. To assess performance, participants then performed a cholecystectomy in an operating theater and the procedures were videotaped. The simulator group dissected the gallbladder 29% faster, were five times less likely to make errors, and were nine times more likely to make progress.[38] A separate but similar study by Grantcharov *et al*[39] supported these findings. The laparoscopic-trained group performed significantly faster than controls and had lower error scores. Such simulators incorporate haptic or tactile feedback. Work by a number of researchers has shown that the addition of haptic feedback in early training may enhance the trainee's sensory perception and facilitate the transfer of skills from the simulator to the operating room.[40,41] A recent systematic review of simulation for laparoscopic surgery included 219 studies, and the authors concluded that: "Simulation-based laparoscopic training of health professionals have large benefits when compared with no intervention and is moderately more effective than non-simulation instruction."[43]

Skills can also be built sequentially with a planned, gradual increase in complexity at a pace that respects individual trainees within a cohort. Such repetition and exercises would not be possible with a real patient. This allows for intensive learning on procedures like venipuncture, central line insertion, and bowel anastomosis.[22,44] Learners can be immersed in a safe environment with "permission to fail" and the opportunity to develop rich, meaningful debriefings with facilitators and coparticipants.[23]

From personal experience, simulation allows trainees to ask the sorts of "what if?" questions they were previously too afraid to ask or that would cause embarrassment in front of patients or colleagues. Also, these learning experiences are usually free of bleeps, phone calls, and various other forms of interruptions that are commonplace in clinical environments. Hence, the learning environment is less stressful than traditional live environments, and stress is recognized as a barrier to learning.[45]

Trainees can also learn not just immediately from mistakes, but can potentially see their natural conclusion, a totally unethical position if a real patient were involved.[46] These educational facets are particularly useful in a craft specialty like surgery, where the limits of each technique can be explored and challenging scenarios re-created to test adaptive responses, rather than having to remain confined to the "zone of clinical safety."[22] Indeed, simulation recognizes that errors are an integral part of human behavior, performance, and development: "The real problem isn't how to stop bad doctors from harming, even killing their patients. It's how to prevent good doctors from doing so."[47] Such experiential learning is a key part of adult learning.[48]

Practical skills teaching also introduces students to the concept of "showing how" and "doing" things as opposed to just rote learning information, which leads to superficial or "surface" learning—as occurs during "cramming" for exams.[49] This allows for a substantial part of the learning curve to be overcome during simulation, increasing safety for real patients and developing more confident surgeons with greater situational awareness.[50–52]

Simulation—not just for trainees

Simulation is not just for trainees, but also for experts learning new techniques. Cadaveric simulations were especially useful in the recent face transplantations.[53] Virtual reality simulation is now providing three-dimensional space and time parameters, thus improving preoperative planning. Chen *et al*[54] showed how virtual reality allowed the construction of accurate three-dimensional models of the liver, individual hepatic volume, and the detailed character of anatomic structures (including vasculature around tumors), and these helped articulate the possibility of intricate liver resection and the operative risks.

Simulation—not just for technical skills acquisition

Surgical training, however, requires the development of far more than technical or procedural skills alone. Gawande *et al*[55] found that 43% of surgical errors involved failures in communication among personnel. Nontechnical skills, like teamwork and communication, are vital areas for consolidation and development throughout surgical training, and this is increasingly being recognized. This necessitates a contextualized approach and an emphasis on simulations rather than simulators.[49]

Recent innovations, like the inflatable operating theater, are allowing entire teams to simulate difficult scenarios at low cost and at relatively high fidelity with authentic equipment (*e.g.*, operating lights, monitors, anaesthetic equipment, etc.).[56]

Such immersive environments will help to develop difficult scenario pattern recognition. In addition, they can build rapport and the interpersonal/interprofessional understanding that is vital for surgical teams to function cohesively and "gel together" in a highly dynamic environment.[5,57,58]

Patient-Focused Simulation

Work by Kneebone *et al*[33] on patient-focused simulation training is a powerful example of the benefits of "simulated patients," where participants engage with a real human being while performing a procedure. This forces technical tasks (previously confined to part-task trainers in social isolation) into a clinical context where effective communication, empathy, insight, clinical judgment, decision making, recognition of limitations, professionalism, coping with stress, and the ability to recognize and respond to each individual can be practiced and assessed in addition to technical skills.[5,20,33,43,59–63] It also helps to encourage "buy-in" to the simulation and suspends disbelief.[54]

Initial work with urinary catheterization and simple suturing under local anaesthetic for medical students underscored such benefits but also showed it was feasible in terms of time, facilities, and resources.[62] These principles can also be extended to more complex surgery—for example, virtual reality simulators for endoscopy.[62] Here, an audio link allows the patient to respond authentically if excessive force or insufflation of air is applied. The trainee thus has rapid and seemingly authentic responses to his or her actions. The trainee can also learn and practice how to respond if an abnormality appears both in terms of the pathology and in terms of the communication with the simulated patient.[60]

Kneebone *et al*[61] have extended their work to laparoscopic surgery. The "LapMentor" laparoscopic cholecystectomy simulator is equipped with haptic or tactile feedback and allows trainees to practice the operation through a range of anatomic variants and get force feedback with greater realism of handling tissues. Authenticity is enhanced with the head and feet of a resuscitation model, artificial skin, surgical drapes, and other team members (surgeon's assistant, anesthetist, and runner nurse, as in Fig. 1). This helps the surgeon learn how to interact with the assistant who controls the laparoscopic camera—a key skill.[58,59] The surgeon must write the operation notes afterward and visit the "patient" in recovery. Webcams allow for recording and analysis of the events post hoc. This format has been replicated for carotid endarterectomy. Such contextualized environments promote deeper, more robust learning than part-task trainers.[64–67]

Translation to the Clinical Environment

However, the traditional concern with simulation has been that it is decontextualized and people behave differently in the "real thing." Roger Kneebone's work has done much to bring context to simulation, but this concern may still remain.[40] So, is simulation-based training transferable to the clinical setting, where it can have a positive impact on actual patient outcomes? There is a growing body of evidence to suggest it can.

Griswold *et al*[68] recently summarized evidence in this area. They found that there was good evidence of skills transfer in pediatric and neonatal emergency situations, tracheal intubation, and central venous line insertions (with decreases in both procedural complications and infections).

The randomized controlled trial by Zendeas *et al*[69] involving laparoscopic inguinal hernia repair showed that simulation decreased procedural time (by 6.5 minutes on the first attempt after randomization) and intraoperative and postoperative complications (5% versus 35% and 3% versus 30%, respectively).[69] More recently, Stefanidis *et al*[70] conducted a single-blind randomized controlled trial to see whether laparoscopic suturing skills developed on a simulator could be transferred and retained in an operating theater. Their results were promising, with 71% of novice participants being trained to proficiency on the simulator being able to retain their skills when transferred to the operating

Fig. 1 Surgeons work through a simulated scenario in the inflatable operating theater. Taken from the BBC, available at: http://www.bbc.co.uk/news/health-11452711.

room.[70] There is, however, much research to do in this area, especially outside of laparoscopic skills.

Disadvantages of Simulation

One could level the criticism that laparoscopic trainers are too abstract, and the tasks too simple and not related to real procedures (although they are improving). By focusing on technical tasks, surgeons can lose the bigger picture, becoming fixated on events in the operating field, to the ignorance of wider concerns and the need for continuity preoperatively, intraoperatively, and postoperatively.

Recent personal experience with a laparoscopic simulator is that sudden, rapid degradations in authenticity can occur when mistakes are made. For instance, bleeding can sometimes manifest itself not just visually on the screen but with rapid and violent shaking of the trocars. Chamarra *et al*[71] have shown that training on virtual simulators without haptics can lead to distortion of the pulling and pushing forces one applies, which are often in excess of what the tissue requires. Virtual reality simulators with haptics and simulated patients are a good form of simulation training.[41,72,73] However, these facilities are not widespread and a typical course would have box trainers and a sugar cube–stacking exercise.

Thus, uptake and accessibility are key concerns. Simulation facilities vary widely between different hospitals, resulting in a “postcode lottery” for trainees.[74] Further concerns have been raised about whether trainees are informed of the facilities available to them and whether they get the appropriate support and tuition in their use from suitably engaged faculty.[74] For some specialties, having the right simulation facilities will be challenging (*e.g.*, cadavers for plastic surgery).

Surgical practice is a team effort involving a number of different specialties and professions. Much work still remains to be done on transferring team skills from simulation to the operating room.[5,72,75–78] Clinical practice is complex, contains uncertainty, and can be emotionally challenging; not all of it can be practiced beforehand.

Cost and space limitations may mean the predominance of a “one size fits all” philosophy—likely to fail some learners who may see it as a “box-ticking exercise.”[79] The technology is advancing so rapidly there may be concern about “white elephants” among budget holders. Finally, an extensive historical review of the use of simulation stated that “the quantity and quality of research in this area of medical education is limited.”[45]

Conclusion

Research is increasingly showing that simulation improves learning and has the potential to meet the needs of trainees and satisfy the regulatory needs of the profession and society. Simulators are becoming more common, more diverse, more authentic, and increasingly incorporated into education programs and professional practice. The judgment of “what the right thing to do is” cannot always be easily taught in the classroom or on a simulation course. At the heart of surgical practice is complex tacit decision making, not just a series of steps. Simulation should be part of the learning experience but cannot replace the requisite clinical hard “graft” and experience a trainee surgeon needs on the “shop floor” supported by good trainers and mentors.

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