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Review Article

Simulation in paediatric urology and surgery, part 2: An overview of simulation modalities and their applications

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Summary
Surgical training has changed radically in the last few decades. The traditional Halstedian model of time-bound apprenticeship has been replaced with competency-based training. In our previous article, we presented an overview of learning theory relevant to clinical teaching; a summary for the busy paediatric surgeon and urologist. We introduced the concepts underpinning current changes in surgical education and training. In this next article, we give an overview of the various modalities of surgical simulation, the educational principles that underlie them, and potential applications in clinical practice. These modalities include; open surgical models and trainers, laparoscopic bench trainers, virtual reality trainers, simulated patients and role-play, hybrid simulation, scenario-based simulation, distributed simulation, virtual reality, and online simulation. Specific examples of technology that may be used for these modalities are included but this is not a comprehensive review of all available products.

Introduction

Healthcare education has evolved rapidly in the past two decades, with changes especially evident in surgical training. There has been a shift from the traditional Halstedian model of time-bound apprenticeship to one of competency-based training [1]. Simulation methodology is now an integral part of training in various surgical subspecialities, especially for technical skills learning. However, it is important to recognize that the role of simulation in surgical education is broader than merely technical skill acquisition. Many adverse incidents in surgical practice arise from or involve failures in domains such as communication, teamwork, and situational awareness, rather than technical expertise [2–4]. Simulation can be employed to promote the learning, practice, refinement, and assessment of both technical and non-technical skills in a patient-safe environment. In addition to allowing learners to make mistakes without adverse patient impacts, simulation also allows for specific rehearsal of rare or unique situations.

In part 1 of this simulation-based medical education (SBME) overview, we introduced the various educational theory concepts that underpin learning clinical environment. The aim of this second part is to provide an overview of the various simulation modalities that can be used to apply these principles and theories.

Open surgery models and trainers

The use of simulators in surgical training is not a novel concept, having been used in many forms for centuries [5]. The majority of these are relatively simple 'part-task' trainers, familiar to most surgeons. Despite their reductionist simplicity, they promote the acquisition of basic skills that form the foundations of surgical expertise. These types of simulators rely on the principles of deliberate practice and feedback to foster development of competency. Part task trainer (PTT) simulators can include cadaveric, synthetic, or animal models that simulate part of a surgical intervention [6]. The use of cadaveric tissue is becoming less common as the availability of alternate bench training models with educational equivalence increases [7]. In some environments, access to and use of biologic tissues is severely limited.

Basic surgical skills (BSS) courses using PTTs are an integral element of early surgical training in many countries, possible even in resource-constrained environments [8]. These PTTs include hooks positioned on a wooden

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board for hand tying sutures, synthetic skin with a laceration for suturing, bowel, or vascular anastomosis using porcine aorta. These courses are often the first introduction of surgical trainee to bench training simulation.

With the introduction of more readily available additive manufacturing techniques or 3D printing, there has been a rapid increase in the number of models for surgical training [9,10]. Hybrid models of surgically altered bovine or porcine tissue, combined with 3D printed chest or abdomen covered in synthetic skin can be used to simulate an oesophageal or duodenal atresia repair. Manufactured anatomical models using 3D printing technology have widespread application in undergraduate teaching (Fig. 1) [11—14]. These are produced with such a high level of realism that they are often indistinguishable from biologic prosections. In a randomised controlled trial of medical students, 3D prints were found to be superior to cadaveric materials for learning external cardiac anatomy [12], perhaps because of increased physical interaction by learners. Additive manufacturing technology is advancing at a rapid rate with promising applications in understanding of complex congenital abnormalities. With the recent introduction of composite and biological printers, *operable* prints of malleable tissue become possible.

It is important to note that these PTTs are not necessarily complex. Construction should reflect fidelity as per Dieckmann [15]. The question of purpose is crucial in simulator design: what is to be learnt from the activity? Conceptual and experiential fidelity is more impactful that the physical fidelity. A simulator needs to confer the skills required, rather than achieve high visual reality.

Figure 1 Additive manufacturing (3D Printing) anatomical models (courtesy of Prof. P. McMenamin).

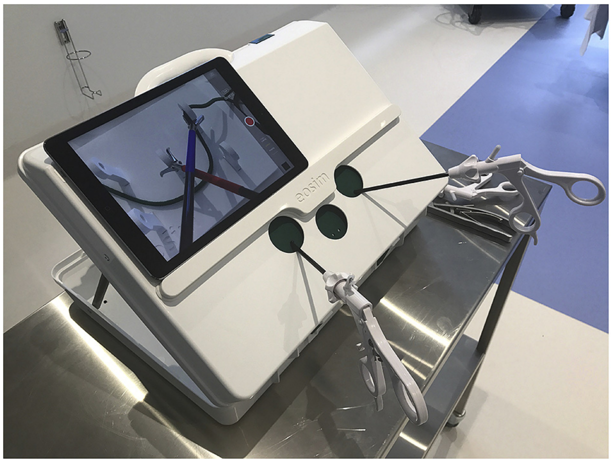

Figure 2 eoSim.

Laparoscopic bench trainers

Laparoscopic surgery has been widely embraced because of the advantages of decreased post-operative pain and shorter hospital stays while offering equivalent outcomes to open surgery in many conditions. However, laparoscopic surgery involves a different skill set to traditional open surgical interventions. In particular, it requires [16]:

- Altered hand-eye co-ordination, as there is no direct vision of the operative field.
- 2D-to-3D perception realization, with the surgeon converting a 2D screen image to the 3D conceptual environment in which they operate.
- Increased fine motor skills as small hand movements are amplified by longer instruments.
- Adaptation to the fulcrum effect of the patient's body wall, causing hand movements to the left of the patient's body to generate instrument movement to the right of the operative field.
- Loss of haptic feedback as well as increased distance of surgeon from target tissues.

These vital skills are generic for all surgical subspecialities and can be acquired prior to patient contact. There is a developing evidence base that training on a laparoscopic bench trainer decreases the time taken to perform a laparoscopic task, improves operative accuracy, decreases errors, and improves overall performance for trainees with no previous experience in real laparoscopic surgery [17].

Bench trainers are ideally suited for application of both mastery learning and deliberate practice. They allow competency of participants to be measured against the benchmark of an expert. Through targeted feedback, improvement of technique toward competence is facilitated. Independent deliberate practice of a specific skill or activity should be coupled with supported sessions with an expert trainer surgeon to provide targeted progression through the various steps to achieve competency. In addition to a formative role in skill acquisition and refinement, bench trainers have been used in summative assessment for certification [18]; such as in the well-established Fundamentals of Laparoscopic Surgery (FLS) [19] programme, developed by the Society of American Gastrointestinal and Endoscopic Surgeons and endorsed by the American College of Surgeons [18]. This programme includes a didactic component presented in a standardised fashion, a simulation-based technical skills component, and a cognitive and technical skills assessment component.

Traditionally, bench trainers were expensive and often only accessible in dedicated training centres. Recently, new and cheaper trainers have become available [20—23], such as the eoSim trainer (eoSurgical, Edinburgh, UK) (Fig. 2). This trainer has proven construct, concurrent, and content validity against more established bench trainers [21]. It also offers access to an online curriculum via in-built motion instrument tracking that allows home-based trainee-driven deliberate practice [24]. Reducing equipment costs allows laparoscopic bench trainers to be used in low-resource settings [18,25—27]. Costs of simulation programmes for early skills development can be offset by decreased operative time as well as reduction in operative complication rates [28—31].

Virtual reality trainers

Virtual reality trainers (VR-T) have similar purpose and underpinning principles to laparoscopic bench trainers, albeit with greater sophistication of technological interface. The vastly increased cost often limits accessibility to training involving these devices. Examples include LapSim (Surgical Science, Göteborg, Sweden) (Fig. 2), and LAP Mentor (Simbionix, Cleveland, OH, USA). Computer-based VR-Ts may be used for both basic and advanced laparoscopic skills training, with an evolving evidence base for use in a surgical curriculum [32].

VR-T use is seen most widely in the field of robotic surgery, supporting its exponential growth in recent years. There are multiple trainers available for robotic platforms, such as dV-Trainer (Mimic Technologies, Inc, Seattle, WA), the Robotic Surgical Simulator (RoSS; Simulated Surgical Systems, Buffalo, NY), and the SEP Robot (SimSurgery, Oslo, Norway) [33]. Some systems require training prior to clinical use, even for expert laparoscopic surgeons.

The safety of the VR environment for skills acquisition is both an advantage and a concern; with potential for creating complacency and false confidence that may translate to the operating theatre environment. The inherent disconnect from consequences of errors and complications can be overcome with use of hybrid simulation to add layers of complexity to the activity and task.

Simulated patients and role-play

Simulated patients (SPs) are widely used in medical education [35—37], driven by the need to enhance communication and patient-contact skills. SPs are particularly valuable in standardised assessment settings such as OSCEs (objective standardised clinical examinations). SPs are trained to represent patients or their relatives in a simulated clinical encounter. Detailed role descriptions ensure 'patient' responses are standardised [35,38] to allow assessment of interpersonal and professional skills of a learner. In some circumstances, specific SP feedback to the learner can be very informative [35]. Often, professional SPs will work and study with real clinical patients to improve their responses and therefore improve the quality of the simulation encounter.

SPs may be involved in both formative and summative activities; promoting development of non-technical skills as well as providing a method by which to assess learner performance in these domains. In addition, SPs may be used in hybrid and scenario-based simulation activities.

Role-play is a widely used educational method for learning about communication skills in medical education. It essentially focuses on inter-personal interaction, with the participants ideally acting in their normal roles, although it can be used to change attitudes by acting in different ones. These activities often include the use of SPs as this enables standardisation of the process and, therefore, it can also be used as an assessment tool. Specific examples include obtaining consent from a parent prior to a urological intervention, informing a parent of an intra-operative complication, or breaking bad news.

Hybrid simulation

Hybrid simulation involves the pairing of PTTs with SPs or other simulation modalities. The combination aims to simulate the complexity of real-world clinical scenarios, enabling the learner to develop or be assessed on multiple skills concurrently [39]. This is often conducted *in situ*, for example emergency department resuscitation bay, outpatient department, or clinical ward to add further contextual reality. An example is a latex skin laceration simulator positioned on a SP arm (Fig. 3) [40]. As in the real-world environment, the learner needs to suture the laceration while interacting with the SP, requiring integration of technical skills with effective communication skills [41]. In urologic application, models are available to allow acquisition of urethral catheterisation technique, while simultaneously interacting with the patient. A more advanced

Figure 3 Hybrid simulation used in a distributed simulation environment [40].

example involves simulated flexible cystoscopy and stent removal, employing a fully draped PTT in a simulated operating theatre requiring communication with both nurse and SP [42]. Complexity could be added with anaesthetic complications, poor support from a nurse, a distressed or uncooperative patient, or an adherent stent which is unable to be removed. Similarly, a laparoscopic nephrectomy model, which simulates acute blood loss, has been used in a urological training capacity to assess crisis management and communication skills within a surgical team using a laparoscopic bench trainer in an operating theatre environment [43].

Scenario-based simulation

Scenario-based simulation is a widely applied form of SBME in surgical training, forming the core of many essential courses such as Advanced Trauma Life Support (ATLS) and Advanced Paediatric Life Support (APLS). Although scenarios are used for practical and technical skills acquisition in this setting, it can be used for development of non-procedural skills such as communication skills, situational awareness, expert judgement, decision-making skills, and cognitive task analysis [44]. The aim of a scenario-based simulation is to develop an instructionally sound activity that fulfils the learning objectives of the session. Scenario development requires a timeline for crucial events and variations in patient observations. Video debriefing is often used for this form of simulation, but should be conducted by adequately trained facilitators to provide safety for the learners [45—47].

The importance of feedback and discussion in learning from scenario-based simulation cannot be overemphasized. The promotion of reflective practice in experiential learning is vital. Complex emotions can be involved, especially where participants have prior clinical experience with poor outcomes.

Scenarios can be conducted within a purpose-built simulation centre (Fig. 4) or *in situ* within an clinical operating theatre, ward, or emergency department environment. Non-technical skills conferred in SBME team-based training can potentially improve patient outcome, although the evidence base for this is still being established [48]. Examples of scenario-based learning include: cardiovascular arrest of a patient on the ward following a laparoscopic pyeloplasty, communication skills with junior theatre staff during complex hypospadias repair, or dealing with an angry and upset parent as they present with a urethral fistula post-operatively in the clinic.

Distributed simulation

Distributed simulation is a disruptive innovation that involves creation of a high-fidelity immersive environment in a portable and inexpensive format, allowing use whenever and wherever it is required [40]. Permitting a simulation team to function in any educational space increases the accessibility to learners while minimizing disruption to local clinical service provisions. Key elements of a real clinical setting are identified and recreated within a contained space, such as an inflatable structure containing a portable operating light, table, drapes, and photographic banners to recreate anaesthetic machines and trolleys (Fig. 5). A pre-recorded audio track is used to enhance experience, recreating authentic background sounds.

This environment has been combined with other simulation modalities including hybrid and scenario-based activities involving non-operative skills such as communication and team working [34]. Advantages of location

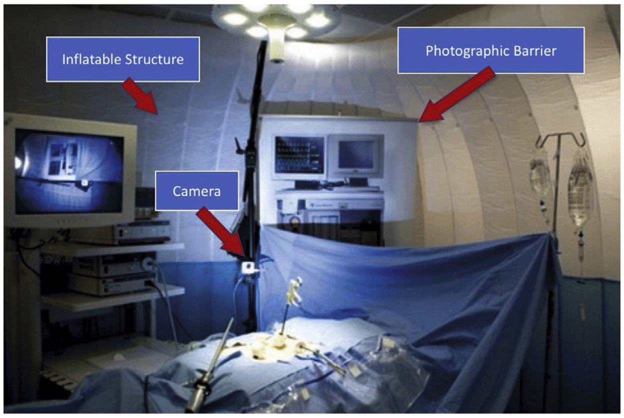

Figure 5 Operating theatre created using distributed simulation [40].

Figure 4 Operating theatre, Monash Children's Hospital Surgical Simulation Centre.

flexibility and reduced resource requirements enhance accessibility and offset disadvantages of reduced quality of video-based debriefing and feedback. Before the introduction of this disruptive innovation, high-fidelity immersive simulation was only possible in a dedicated simulation centre. Potential future applications in low-resource settings and countries exist, but have not yet been subject to trial.

Virtual reality and online simulation

Virtual reality simulation has gained popularity in recent years, with examples including interprofessional and communication skills learning through virtual human experience [49], assessment of fine motor skills prior to a clinical encounter [50], and team training in an operating theatre [51]. Links to interactive gaming environments are clear in examples such as Zero Hour: America's Medic, a first-person video game designed to train first responders to mass casualty incidents [52]. While concerns about cost and false confidence exist, the interaction provides a good introduction to the principles of triage and first-line patient management.

Online learning resources are becoming more widespread in paediatric surgical and urological training. Resources such as WeBSurg allow both trainees and practicing surgeons to view procedures prior to clinical contact [53]. This has been incorporated in the formation of a Global Virtual University [54], aiding the formation of virtual surgical communities of practice [55]. A urological example of online resources is the CEVL interactive system [56]; in this online educational module, the entire operating room staff are able to train with the system and hence improve performance with a paediatric robotic-assisted laparoscopic pyeloplasty.

Conclusions

There are many different modalities of simulation applicable to surgical training. Some of these are readily available and other are more expensive; located in specialised surgical simulation centres. Advances in simulator design have resulted in decreased cost and bring aspects of SBME within the reach of all departments, even in resource-constrained environments. Surgical simulation does not have to be expensive or time-consuming to be effective and may therefore be incorporated into busy surgical timetables. Accessibility promotes self-directed learning by the surgical trainee but this needs to be augmented with regular observation and feedback from an expert trainer.

Regardless of the technology used in educational activities, the principle focus must be on the purpose or learning intention. Simulation does not have to recreate an exact clinical environment or procedure to be useful; however, high conceptual and experiential fidelity is important. Technologically advanced mannequins and simulators may be imagined offering greater fidelity, but this is not always true. A simple hook on a board has an excellent conceptual fidelity if the purpose is for teaching hand-tying of knots. The drive for more technology to be incorporated into simulation needs to be balanced with the purpose of the learning experience. With all simulation-based education, clarification of learning objectives for an activity can aid identification of the most appropriate modality to achieve these.

Conflict of interest

None.

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