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The Role of Simulation in Endoscopic Sinus Surgery Training

Benjamin Stew and Eng Ooi

Additional information is available at the end of the chapter

Abstract

Surgical simulation is an effective tool used to teach many of the fundamental skills required to be a surgeon. Simulation-based education with directed practice in surgical training allows repeated practice in an environment to learn surgical skills, which do not cause harm to patients. There are several simulators developed for endoscopic sinus surgery training. Some simulators have undergone validation studies with regard to developing skills necessary to perform endoscopic sinus surgery. This book chapter will review the currently available sinus surgery simulators that have undergone validation and evaluate their potential role in surgical training.

Keywords: simulation, sinus, surgery, training

1. Introduction

Rhinology and endoscopic sinus surgery (ESS) have advanced considerably over the last two decades owing to advances in technology and research. Accessing the skull base can now be achieved via a transnasal endoscopic approach, and our ability to deal with complex pathology has evolved given the dramatic improvement in our understanding of anatomy and development of new surgical instrumentation. However, there remains a need to achieve competency with basic ESS, which includes control of an endoscope as well as using instruments within the tight confines of the para-nasal sinuses close to vital structures such as the orbit or skull base. ESS requires familiarisation with the fulcrum effect of the instruments and the psychomotor constraints of the endoscopic interface. Resident participation in the operating room is associated with lengthier operative times [1, 2] and increased complication rates in ESS [3, 4]. Hence, there is a need for sinus surgery simulators to allow surgical training of

residents in a safe environment thereby reducing complications. This chapter provides an updated review of ESS simulators and describes how simulation can be used effectively to improve training.

2. Brief overview of endoscopic sinus surgery

ESS is indicated in patients with chronic rhinosinusitis who fail to respond to medical therapy [5]. Minor complication rates are reportedly 5%, with postoperative epistaxis the most common. Major complication rates are less than 1%; however, these include orbital and carotid artery injuries, which are potentially devastating for the patient [6]. ESS is also now being extended to include the management of dysthyroid eye disease and epiphora [7, 8], and the surgical management of benign [9, 10] and malignant [11] sinonasal and skull base tumours.

3. Surgical training

Traditionally surgical training required trainees to undergo a 'surgical apprenticeship' where they would work long hours and perform a large number of cases in order to gain competency. However, surgical competency does not always correlate with the number of cases performed. Critical to the achievement of expertise is the number of hours spent in deliberate practice [12]. Most developed countries advocate for safe working hours which is usually to restrict the working hours of residents/junior doctors in order to avoid fatigue and improve patient safety. There is therefore a need to provide trainees with the opportunity to undertake deliberate practice within the confines of these safe working hours. While traditional didactic teaching and textbooks remain of utmost importance, it has been demonstrated that the current generation of trainees is more amenable to technology and alternative teaching methods [13]. Interactive, hands-on experiences with the opportunity to learn through trial and error are considered more enjoyable and effective [14].

This evolution, with respect to surgical skills acquisition, requires a change in the traditional methods of training. It is not always possible or safe for a trainee to practise and acquire the surgical skills that were traditionally learned in the operating theatre during operations on patients. Alternatives such as watching live or recorded surgery and cadaveric dissection have become an essential part of the way in which training is delivered. Cadaveric dissection remains the gold standard of ESS training and forms part of the otolaryngology curriculum in many training programmes [15]. Factors, such as cost and cadaver availability, however, limit the amount of time and opportunity that a trainee may have to work on their skills at cadaveric courses.

In areas, outside of medicine where significant harm is associated with error, simulation has been successfully implemented. Industries, such as aviation, use simulation for the purpose of providing a safe environment for pilots to practise, which reduces training time through

improved retention of information. Simulation in surgery is rapidly developing and becoming a popular way to train both novice and skilled doctors. Repetitive practice of a well-defined task and feedback allow for an accelerated and ultimately safer learning curve [16]. Simulation has the potential to improve surgical training including techniques and understanding, advances in instrumentation, patient safety and time allocation in theatre [3].

4. Simulation

Surgical simulators vary considerably and range from devices that can be used to teach simple skills through to more complicated techniques. **Table 1** summarises the different types of simulation models that exist as well as their advantages, disadvantages and best use.

Many sinus surgery simulators have been developed around the world varying from simple models constructed from regular household items to highly complex virtual reality models. Physical models described in the literature include low-cost, low-fidelity models through to high cost and intermediate fidelity ones. The major limitation of synthetic models is the unrealistic anatomy and consistency of the tissue, which lacks mobility and lifelike strength. Despite this, many have proven to be useful training tools for ESS trainees. Several studies have shown that the technical skills acquired on low-fidelity physical models might confer the same degree of benefit as high-fidelity training models, such as cadavers. This was because the learning process was considered to be more important than the physical substrate [18]. The Georgetown low-cost sinus trainer costs $5 and allows the trainee to practise basic endoscopy and sinus surgery skills including recess probing, targeted injections, removal of a suture, removal of a foreign body and antrostomy creation using an egg [19, 20]. Witterick's group from the

Simulation	Advantages	Disadvantages	Best use
Bench models	Cheap, portable, reusable, minimal risk	Low fidelity, basic tasks, tasks are not surgical operations	Basic skills for novice learners, discrete skills
Live animals	High fidelity, can practise haemostasis	High cost, ethical considerations, anatomical differences between animals and humans, single use only	Advanced practice of dissection skills
Cadavers	High fidelity, only 'true' anatomical simulator	High cost, limited availability, single use, tissue compliance different from live surgery, infection risk	Advanced procedural knowledge, practice of dissection skills
Human performance simulators	Reusable, high fidelity, data capture, interactivity	Cost, maintenance (upkeep), limited technical applications	Team training, crisis management
Virtual reality surgical simulators	Reusable, data capture, minimal setup time, photorealism, potential for haptic feedback	Moderate to high cost, maintenance (upkeep), acceptance by trainees	Basic and advanced endoscopic sinus surgery

Table 1. Types of surgical simulators available [17].

University of Toronto developed a low-cost, low-fidelity, easily constructed simulator for $20 with five different training modules and demonstrated that training on the model had a positive impact on ESS skills [21, 22]. More recently, the University of Texas [23] have produced a silicone injection moulded ESS simulation model at low cost and testing revealed high ratings for both face and construct validity. Storz have crafted a lifelike training model based on real computed tomography images. This can be purchased but is considerably more expensive than those already discussed and furthermore the model has not undergone adequate validation [24].

Live animal and cadaveric simulation offers trainees excellent handling fidelity. They also offer the advantage of possessing tissue realism including bleeding. Tissue realism is, however, variable, depending on whether the cadaver is embalmed or fresh frozen. Embalmed cadavers do not exhibit the same subtle tissue characteristics of fresh frozen tissue. Normal surgical instruments may be used on either, and recognised surgical procedures may be undertaken. Live animal simulation is not permitted in all countries including the UK, and therefore, cadaveric simulation is more common. ESS simulation on cadavers has many advantages over physical models, but it relies on cadaver availability [25, 26]. The most important advantage is that cadavers represent the only true anatomical model of the human para-nasal sinuses. Unfortunately, cost and ethical approval are two factors mitigating widespread practice. Cadaveric simulation also poses an infection risk and specimens are limited to single use. The ovine sinus simulator utilises a cadaveric sheep's head whose sinus configuration has some similarities to human anatomy, including the lateral position of the maxillary sinuses, posterosuperior position of the skull base and midline of the position of the septum. The sheep's head, however, is longer, lacks a sphenoid sinus and has poorly aerated ethmoidal cells rendering ethmoidectomy unrealistic [27].

Although early simulators were largely cadaveric or synthetic, technology advancement has resulted in a boom of virtual reality simulators. Virtual reality (VR) simulators have the capacity to overcome the inadequacies of physical and cadaveric models and allow trainees to practise a standardised, task with objective feedback. Sinus surgery naturally lends itself to computerised simulation given the use of high-definition screens and requirement of the operator to work from a 2D image for a 3D procedure [28]. One of the earliest VR simulators was the Madigan endoscopic sinus surgery simulator (ES3), a simulator developed in collaboration with Department of Defence contractor Lockheed Martin Corporation in 1996. The operating system allows for visual and haptic feedback, offers instruction and analyses performance. It facilitates ESS training through provision of spatial relationships and depiction of sinus anatomy, as well as allowing the trainee to use common surgical instruments and has three difficulty modes depending on ability. Other VR simulators have been described in the literature. However, only three other VR simulators have undergone validation studies (**Table 3**). The McGill simulator for ESS (MSESS), developed by the National Research Council of Canada, represents the most advanced VR ESS simulator that is currently available to purchase. It has the ability to simulate an ethmoidectomy and sphenoidotomy secondary to its high optical resolution and tissue removal algorithm. The performance metrics relating to quality, efficiency and safety demonstrated a dichotomy between novice and senior surgeons [29]. Widespread adoption of the MSESS in training may, however, prove unrealistic as a consequence of its cost.

The Flinders sinus surgery simulator (FSSS) is a prototype that was developed at Flinders University and was funded by The Garnett Passe and Rodney Williams Memorial Foundation. It is a high-resolution haptic simulator that has advanced photorealism but a relatively basic tissue removal algorithm and lacks realistic haptic feedback. Unfortunately it is not currently available for purchase and is not being used as part of a training programme. The Dextroscope is a commercial FDA approved simulator developed by volume interactions. It facilitates reconstruction of images from a patient's computed tomographic scan. The simulator uses virtual tools through stereoscopic glass; however, it lacks force feedback and is time consuming.

5. Validation

Validation refers to the process of testing the simulator, and it can be defined as outlined in **Table 2**.

Validation is an essential process prior to the implementation of a simulator into training. Face validation is simplest and is often undertaken first and refers to the simulator looking and feeling authentic. In the case of ESS simulation, it requires judgement from a person familiar with ESS, which is typically an expert rhinologist. In isolation, it is never sufficient and requires further evaluation before acceptable conclusions, regarding its ability to teach and train, are able to drawn. It is fundamental that a surgical simulator undergoes construct validation. Construct validity refers to the assessment of the quality of the simulator and its ability to carry out what it was designed to do. This may be the teaching of anatomy or ESS skills and should have the ability to distinguish novices from experts. Fundamentally, the goal of surgical simulation is to improve surgical performance and efficiency. Predictive validity represents the highest level of testing. A sinus simulator that has undergone predictive validation has the ability to teach those skills that can be translated into improved operative performance.

There are seven physical trainers, one cadaveric model and four VR platforms that have undergone validation as ESS simulators (**Table 3**).

5.1. Physical bench models

There are a number of physical bench models that have undergone validation in the literature. All seven of these models score well with respect to teaching endoscopy skills and hand eye coordination. Efficiency of task completion improved with practice. Camera navigation and instrument handling became more accurate. These observations were particularly apparent among medical students and resident learners. While these models lend themselves to these basic tasks, their use as a training tool for ESS would appear limited. They do not aid surgical decision-making nor have the realism to teach surgical anatomy. The low-fidelity sinus simulator developed by the University of Toronto was, however, able to demonstrate that its use prior to cadaveric dissection improved surgical performance. Given the ease of construction, low cost and overall entertainment factor, these low-fidelity physical models may be implemented into training to teach novices and junior trainee's simple skills in ESS.

	Definition	Use
Face	Having experts review the contents of the test to see if it measures what it is supposed to measure	To initially design a test (subjective)
Content	An estimate of the validity of a testing instrument based on a detailed examination of the contents of the test item	Experts review whether or not the test contains the logical steps and skill used in a procedure (subjective)
Construct	A set of procedures for evaluating a testing instrument based on the degree to which the test items identify the quality, ability, or trait it was designed to measure	To differentiate between novices and experts (objective)
Predictive	The extent to which the scores on a test are predictive of actual performance	Test used to measure skill predicts who will actually perform the procedure well and who will not in the operating room. This provides the most clinically useful assessment (objective)

Table 2. Validity definitions—reproduced from Ref. [16].

5.2. Cadaveric/ovine models

Cadaveric simulation, despite being regarded as the gold standard over physical and VR models, is yet to demonstrate that its use improves operating performance. Nonetheless trainees do consider the experience of training on cadavers to be highly valuable [15]. The sheep's head model as a sinus simulator for the purpose of ESS training has undergone face and construct validation [27, 45]. Awad et al. suggest that it used as a step in the simulation ladder, prior to in-vivo practice, as it represents an opportunity to focus on basic endoscopic rhinological procedures in conjunction with training on VR and cadaveric models. They describe a task specific checklist and global assessment tool to evaluate the performance of the operator. The simulator demonstrated a clear relationship between surgical experience and task performance.

5.3. Virtual reality models

The most comprehensively validated VR sinus simulator is the ES3. The ES3 has undergone extensive validation and to date represents the only VR ESS simulator to have predictive validity. It been shown to train novices in sinus surgery, so that they can perform to a level within 80% of an experienced surgeon. Surgical performance within the operating theatre, as judged anonymously by senior surgeons, was better following simulation training. The positive impact of prior simulation training was reflected in the fact that surgeons reported improvement in confidence and observed reduced overall operating time. The ES3, however, is not currently available to purchase for residency training programmes. The MSESS has also been systematically validated and research shows that it is able to differentiate between levels of experience based on task performance. Violation of no-go zones and the amount of mucosa resected over the lamina papyracea were both significantly higher in novices. The simulator demonstrates adequate realism and serves as a useful training option for medical students through to senior surgeons. The FSSS is a prototype that is currently not available for purchase

Simulator	Analysis	Validity
Physical bench model		
• SIMONT	Stamm et al. [30]	Face
• Storz Sinus model	Fortes et al. [31]	Face
• Oklahoma FESS model	Briner et al. [24]	Face
• Georgetown Sinus trainer	Burge et al. [32]	Construct
• Toronto Sinus simulator	Steehler et al. [20]	Face, content & construct
• Texas ESS model	Steehler et al. [33]	Construct[*]
• Seattle Sinus task trainer	Leung et al. [21]	Predictive
	Wais et al. [22]	Face
	Chang et al. [23]	Face, content & construct
	Harbison et al. [2]	
Cadaveric/ovine		
Sheep's head model	Awad et al. [27]	Face, content & construct
	Awad et al. [34]	
Virtual reality		
• Madigan (ES3)	Rudman et al. [35]	Face
• McGill (MSESS)	Edmond et al. [36]	Predictive
• Flinders (FSSS)	Uribe et al. [37]	Face & construct
• Dextroscope	Arora et al. [38]	Construct
	Fried at al. [39]	Construct
	Solyar et al. [40]	Construct
	Fried et al. [41]	Predictive
	Varshney et al. [29]	Face & construct
	Dharmawardana et al. [42]	Face & content
	Diment et al. [43]	Construct
	Caversaccio et al. [44]	Predictive[*]

[*]Unable to prove.

Table 3. Summary of validated sinus surgery simulators.

and it is not incorporated in a training programme. As a simulator, it was considered better among novices compared to experts in terms of usability and usefulness. While tissue texture and deformity was considered realistic, the haptic behaviour of the rigid endoscope was not. Task performance was significantly different between novices and experts demonstrating construct validity for the FSSS. The Dextroscope failed to demonstrate a significant improvement in a trainees' anatomical knowledge following its use and lacks any proven validity.

5.4. Limitations

There have been numerous publications describing the validation of sinus simulators that now exist but like many other specialties, interpreting the accuracy of these studies can be problematic [46]. Typically, authors describe simulators that have been evaluated with a view to validation. However, the quality of the study, outcome measures and statistical analysis lack accuracy and clarity rendering the conclusions weak. Statements of effectiveness and representativeness by an expert in the field do not constitute high-level evidence. Face validity relies on expert opinion but unfortunately no universal consensus exists as to what constitutes an expert. Furthermore, novices are poorly categorised and range from students to middle tier trainees. Several of the above studies, while well constructed, involve low sample sizes and therefore lack the power to make valid conclusions. This lack of standardisation in terms of recruitment and outcome reporting make it very difficult to compare one simulator with another. Therefore, choosing one simulator over another is difficult. Aside from the limitations that exist in terms of validation, simulators are expensive and require frequent maintenance.

6. The future of simulation

The role of simulation in surgical training is already well established. Simulation serves to improve the technical skills required of a surgeon within both otolaryngology and other surgical subspecialties [47, 48]. The widespread implementation of simulation in training is influenced by many factors such as cost and effectiveness. The provision of simulation opportunities for surgical trainees depends on departmental and training programme philosophy, pre-existing access to cadaveric workshops and courses, and ultimately a need to change practice. Undoubtedly, high-fidelity models will become increasingly available and cost effective and allow departments to utilise simulation for assessment of surgical skills acquired rather than as a training tool. This may be as part of trainee assessment and recruitment or revalidation. Competency, which currently relies upon expert opinion or logbook analysis, may be superseded by simulation. Laeeq et al. [49] demonstrated that a minimum of 55 sinus surgeries are required to achieve competency in all steps of FESS; however, training requires formative and summative assessment and not simply operative cases only. Procedural-based assessments, which are routinely used in many training programmes for assessment, are subject to the inherent bias of the well-liked trainee scoring highly. Objective structured assessment of skills (OSATS) have been developed and shown to be effective in the assessment of surgical competence [33]. Their application to a simulation task that has the potential to be blinded and independently reviewed is an exciting possibility. Alternatively training departments could use the objective scores that are given by simulators for score specific tasks.

7. Key points

- Simulation provides trainees of all abilities an opportunity to improve their skills in a safe, low-risk environment

- ESS simulators exist with inherent advantages and disadvantages

- Simulation can be used to practise simple and complex skills

- Validation is a fundamental aspect of simulation development

- Simulation has a key role to play in the evolution of surgical training

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