Journal of
*Otorhinolaryngology, Hearing and Balance Medicine*

MDPI

*Commentary*

# An Evidence-Based Framework for Simulation in Endoscopic Sinus Surgery: A Graded Approach to Training with 3D-Printed Models

**Timothy Davies * and Samuel Leong**

Liverpool Head and Neck Centre, Aintree University Hospital, Liverpool L9 7AL, UK
* Correspondence: timothy.davies@nhs.net

**Abstract**

Background: Endoscopic sinus surgery (ESS) is a core operative technique in otolaryngology and is associated with a steep learning curve due to complex sinonasal anatomy, limited depth perception with two-dimensional endoscopy, and the requirement for precise bimanual coordination. Given the potential for serious complications, including cerebrospinal fluid leak and visual loss, simulation provides an important opportunity for trainees to develop technical skills in a controlled environment without risk to patients. Recent advances in three-dimensional (3D) printing have enabled the development of high-fidelity models for ESS training. Methods: We describe an evidence-based, graded approach to ESS simulation using two commercially available 3D printed sinus surgery models tailored to the trainee's stage of training. Early-stage simulation focuses on development of anatomical orientation, endoscopic hand–eye coordination, tissue handling, and basic procedures such as middle meatal antrostomy and anterior ethmoidectomy. Advanced simulation targets more complex procedures, including frontal and sphenoid sinus surgery, transsphenoidal approaches, and management of intraoperative complications. Results: Validation studies demonstrate high face and content validity for both models. Early-stage simulators support acquisition of fundamental technical skills, while advanced models allow simulation of complex anatomy, pathology, and operative complications. Conclusions: A structured, stage-appropriate simulation strategy using high-fidelity 3D printed models may enhance technical skill acquisition and support safe and effective training in endoscopic sinus surgery.

**Keywords:** endoscopy; paranasal sinuses/surgery; otorhinolaryngologic surgical procedures; simulation training; education; medical; graduate



Academic Editor: Agnieszka Szczepek

Received: 5 March 2026
Revised: 15 April 2026
Accepted: 18 April 2026
Published: 22 April 2026



## 1. Introduction

Simulation is a key adjunct to medical training that allows a learner to acquire new skills without exposing patients to risk of harm [1]. Simulation in surgical training allows trainees to practice operative techniques in a carefully controlled environment, with the potential for repeated exposure to rare or complex elements of operations. As such, simulation now forms a key adjunct to surgical training curricula globally [2]. Endoscopic sinus surgery (ESS) is a key operative technique for otolaryngology trainees to master. This technique forms the basis of management of a broad range of emergency and elective ENT practice, including epistaxis, sinonasal malignancy, and chronic rhinosinusitis [3]. There are a number of aspects of this operative technique that make it technically challenging to learn and as such, a technique where simulation should be used as an adjunct to in-theatre training [4]. Firstly, operating using an endoscope connected to a camera and screen is technically and ergonomically challenging [5]. Secondly, two-dimensional endoscopes limit depth perception, which must be overcome to master the hand–eye coordination required for developing proficiency in ESS [6]. Thirdly, sinonasal anatomy is conceptually challenging to grasp, with a broad range of interpatient anatomical variations. Unlike open surgery, ESS is typically a one-surgeon procedure where the surgeon holds the endoscope in one hand and surgical instrument in the other. Conventional learning to undertake ESS is therefore mainly through observation and is supplemented with some hands-on experience and attendance at instructional courses. As such, simulation of endoscopic sinus surgery with challenging elements of physiological and pathological anatomical variation is essential [5].

The nature of complications of ESS, including loss of vision, CSF leak, and meningitis, outlines the importance of simulating ESS for novices, to ensure that any risk to patients through inexperience is mitigated [3]. Multiple previous models for simulation of endoscopic sinus surgery have been reported, with cadaveric and animal models forming the basis for previous efforts at simulating this operative technique [7–9]. The recent advent of 3D printed sinus surgery simulation models has revolutionised the potential for simulation in this discipline. The technology has driven a huge amount of interest in the development of high-fidelity models for surgical training, but few have been able to achieve the scalability for commercial production.

Here, we describe an evidence-based, multi-model approach to simulation in sinonasal surgery aimed at ensuring that learning outcomes are relevant for learners, based on their level of experience.

## 2. Sinus Surgery Simulation

During progression through otolaryngology training, training needs in ESS evolve. Early years trainees aim to develop skills in interpretation of intraoperative anatomy, tissue handling, instrument handling, and completion of basic operative techniques. The educational outcomes for advanced endoscopic sinus surgery are likely to be aimed at complex elements of operative practice, management of complications, and operating in advanced pathology (Table 1). It is important that simulation in ESS is designed and organised to allow trainees to address training needs relevant to their stage of training. Here, we describe a protocol of graded exposure to two commercially available 3D printed sinus surgery simulation models, aimed at otolaryngology trainees (Figure 1).

**Table 1.** A table to demonstrate learning outcomes for simulation in endoscopic sinus surgery, based upon level of learner experience.

| **Learning Outcomes in Endoscopic Sinus Surgery Simulation** | |
|---|---|
| **Early Years Trainees** | **Advanced Endoscopic Sinus Surgery** |
| Ergonomics—bimanual dexterity | Advanced sinonasal anatomy |
| Tissue handling | Frontal sinus surgery |
| Instrument handling | Transsphenoidal approach to pituitary |
| Sinonasal anatomy | Cerebrospinal fluid leak repair |
| Middle meatal antrostomy | Internal carotid artery injury |
| Anterior ethmoidectomy | Advanced pathology |

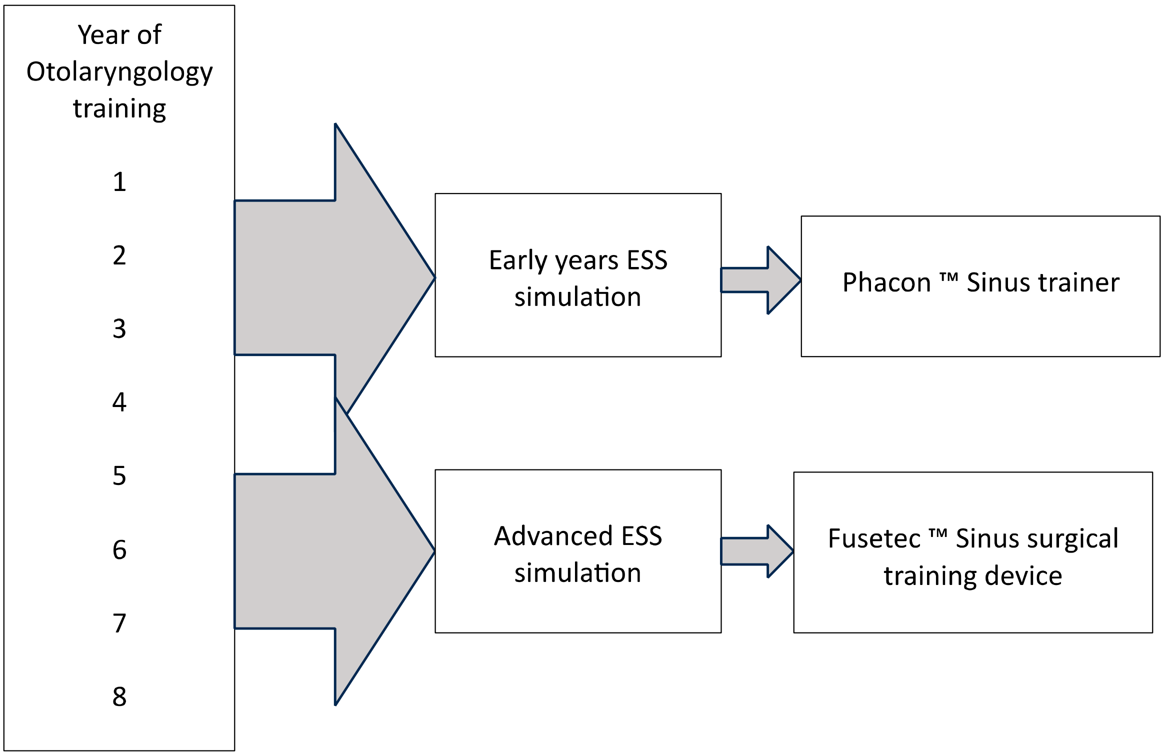


**Figure 1.** Flow diagram demonstrating simulation requirements and the most appropriate model according to years of training. The training years depicted relate to UK surgical training, which typically spans 8 years; however, exposure may be adjusted according to the duration of an individual's surgical training.

### *2.1. Simulation in Early Years Endoscopic Sinus Surgery Training*

Early years otolaryngology trainees are likely to target the development of bimanual dexterity, anatomical knowledge, tissue handling, and basic operative techniques as learning outcomes for simulation in ESS. The Phacon™ (PHACON GmbH, Leipzig, Germany) sinus trainer provides an excellent model to address these key learning outcomes. This sinus simulation model was first described by Alrasheed et al. in 2017, with assessment of the face, content, and construct validity of the model reported [10]. The strengths of the model were found to lie in the face validity of the appearance and bony elements, as well as the content validity of anatomical elements and the potential for developing bimanual dexterity. It is the opinion of the authors that the model's reported strengths align with key early years learning outcomes for ESS simulation. Furthermore, the outcomes for simulation using the Phacon™ sinus trainer were externally validated by Alwani et al. in 2019 and Leong in 2023 [11,12]. Both groups found that the content validity of anatomical elements of the model, as well as the potential for developing operative techniques, were high. Alwani et al. reported that 75% and 58.3% of trainees felt that the model was useful for middle meatal antrostomy and anterior ethmoidectomy, respectively [11]. Furthermore, Leong et al. reported that 92% of respondents felt that the model was useful for developing hand–eye coordination, and 90% felt that the model was useful for developing skills in endoscopic sinus surgery [12].

The Phacon™ sinus trainer is not without its limitations, which the authors feel limit its utility for simulation in advanced elements of ESS. Firstly, the reported literature outlines the lack of content validity of this model in simulating frontal sinus surgery, a key element of advanced ESS. Alrasheed et al. reported a score of 3.8/5 on initial validation of the model for frontal sinus operating [10]. This was confirmed on external validation by Alwani et al., who reported 50% of trainees felt the model was useful for frontal sinus surgery [11].

Furthermore, Leong et al. reported that the consultant faculty felt that the model had low utility in more advanced procedures of ESS, including frontal sinus surgery [12]. An additional weakness of the Phacon™ sinus trainer is the face validity of the sinonasal mucosa of the model [10–12]. This is an important consideration in simulation for advanced ESS, as mucosal elements of operative techniques form key elements of frontal sinus and transsphenoidal operating [13,14]. As such, the content validity of the mucosa of the model is essential for simulating these techniques well.

*2.2. Simulation in Advanced Endoscopic Sinus Surgery*

Simulation of advanced elements of ESS should include frontal sinus surgery, sphenoid surgery including transsphenoidal approaches to the pituitary, as well as simulation of advanced pathology and operative complications. The Fusetec ™ (Fusetec Pte Ltd., Adelaide, Australia) sinus surgical training device affords trainees with the opportunity to develop their skills in all these domains. There are several available models to choose from. The models are based on CT scans of actual patients, and each has a different complexity of sinonasal anatomy. The manufacturers have been able to develop composite materials to mimic pathology such as nasal polyps and tumours. In addition, the models have additional modules which incorporate mechanical pumps to simulate blood flowing through arteries and cerebrospinal fluid. The Fusetec models have been used at training courses since 2020. Suzuki et al. in 2022 was the first to report high content, face, and construct validities, following a course in Japan where delegates were instructed remotely by study senior teaching faculty based in Australia [15]. Suzuki et al. reported that, in addition to a content validity of >80% in MMA and AE, the model also had a content validity of >80% in simulating frontal sinus surgery and sphenoid sinus surgery [15]. As such, it is the opinion of the authors that this model provides the best opportunity for simulation of advanced endoscopic sinus surgery. It is essential that simulation of advanced ESS also includes the simulation of potential catastrophic complications of operative management. Candy et al. 2024 reported the pilot validation of this model in the simulation of a number of additional elements of advanced ESS [16]. They reported high content validity for simulation of transsphenoidal pituitary surgery, as well as CSF leak and carotid artery injury. Furthermore, Candy et al. confirmed the face validity of their model by monitoring the heart rate of trainers during and shortly after simulation of carotid artery injury, confirming a significant rise, and, as such, the simulation of a highly stressful intraoperative complication [16].

## 3. Discussion

Recent advances in 3D printed sinonasal simulation models have revolutionised the potential for simulation in ESS. The COVID-19 pandemic was a catalyst for the development and distribution for a number of 3D printed simulation models, as conventional simulation environments were no longer available [17]. Furthermore, elective operative practice was paused across the globe, and, as such, learners and trainees were in acute need for simulated surgery to subsidise their experience lost during the pandemic [18]. It is our hope that continued use of 3D printed sinus surgery simulation models, with graded exposure as outlined above, will form the basis of simulation in ESS for otolaryngology trainees in the future.

Prior to the advent of 3D printed models, animal and cadaveric specimens formed the basis of simulation in ESS. Valentine and Wormald developed the sheep model that allowed simulation of advanced sinus surgery, including carotid artery injury [19]. The use of cadavers is well established in all aspects of surgical training [20]. Donoho et al. reported the use of a cadaveric model in the simulation of endoscopic skull base surgery and carotid artery injury [7]. There are a number of factors that limit the widespread uptake of these models. Firstly, preparation of animal and cadaveric models is labour intensive, especially when simulation of advanced elements of ESS is undertaken. Preparation of the specimens requires a regulatory approved laboratory, which carries a high cost of set up and upkeep [16]. Secondly, both cadaveric and animal models are limited by the baseline anatomy of the human or animal donor. Cadavers have different anatomies, rendering variable learning experience by the delegate who may undertake dissection without the benefit of scans.

As such, the quality of simulation, which is dependent upon sinonasal anatomy, may be limited by the cadaver or animal used. Furthermore, there are a number of religious and ethical considerations that may limit the use of cadaveric and animal models in surgical simulation [21,22]. A great strength of the 3D printed models, when compared to animal or cadaveric models, is the capacity to simulate pathology. The Fusetec ™ model allows simulation of advanced elements of sinonasal pathology, such as nasal polyps and pituitary tumours [15,16]. Whilst the bony approaches to ESS operative techniques can be simulated using animal and cadaveric models, simulation of operative management of pathology is lacking. The authors recognise that cadaveric and animal models can still form an important element of simulation in ESS, and that anatomical and mucosal elements of these models are excellent when compared to 3D printed models. Suzuki et al. (2024) undertook a direct comparison of cadaveric models and 3D printed models in a simulation in ESS [23]. They found that the results of the Objective Structured Assessment of Technical Skills, a validated tool for assessment of technical competence and operative performance, were comparable between the two models [23]. Delegates are able to benchmark against their peers and to observe faculty demonstrations of the surgical technique on the same model.

A number of limitations of 3D printed models exist and should be considered when integrating them into training in endoscopic sinus surgery. Although these models achieve high anatomical fidelity, they often fall short in replicating the biomechanical properties of living tissue, particularly with regard to mucosal handling, bleeding and tissue responsiveness. This may limit their effectiveness in simulating key aspects of advanced procedures, where tactile feedback and dynamic tissue behaviour are critical. Furthermore, the cost of production will limit their accessibility, particularly in resource limited settings.

It is the opinion of the authors that 3D printed models should form the basis of simulation in ESS. It is important that trainers recognise the skill and experience level of their trainees and tailor the aims of simulation accordingly. Graded exposure to ESS simulation should form a key adjunct to conventional surgical training, and the recent advent of high-fidelity 3D printed models is an excellent vessel for the delivery of this simulation.

**Author Contributions:** Conceptualization, T.D. and S.L.; methodology, T.D. and S.L.; writing—original draft preparation, T.D. and S.L.; writing—review and editing, T.D. and S.L.; supervision, S.L.; project administration, T.D. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AE | Anterior ethmoidectomy |
| CSF | Cerebrospinal fluid |
| CT | Computed tomography |
| ENT | Ear, nose, and throat |
| ESS | Endoscopic sinus surgery |

| | |
|---|---|
| MMA | Middle meatal antrostomy |
| 3D | Three-dimensional |

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