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An update on simulation training in rhinology: a systematic review of evidence

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Main Article

Laura J Brennan takes responsibility for the integrity of the content of the paper

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Abstract

Background. Rhinological procedures demand a high degree of technical expertise and anatomical knowledge. Because of limited surgical opportunities, ethical considerations and the complexity of these procedures, simulation-based training has become increasingly important. This review aimed to evaluate the effectiveness of simulation models used in rhinology training.

Methods. Searches were conducted on PubMed, Embase, Cochrane and Google Scholar for studies conducted between July 2012 and July 2022. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis ('PRISMA') protocol defined a final list of articles. Each validated study was assigned a level of evidence and a level of recommendation based on the Oxford Centre of Evidence-Based Medicine classification.

Results. Following exclusions, 42 articles were identified which encompassed six types of simulation models and 26 studies evaluated validity. The rhinological skills assessed included endoscopic sinus surgery ($n = 28$), skull base/cerebrospinal fluid leak repair ($n = 14$), management of epistaxis and/or sphenopalatine artery ligation ($n = 8$), and septoplasty and septorhinoplasty ($n = 6$). All studies reported the beneficial impact of their simulation models on trainee development.

Conclusion. Simulation training in rhinology is a valuable adjunct to traditional surgical education. Although evidence is of moderate quality, the findings highlight the importance of simulation-based training in rhinology training.

Introduction

Simulation-based training is rapidly becoming a vital aspect of surgical training. It refers to a structured educational approach that uses simulators and simulation models to replicate surgical scenarios and procedures in a controlled environment.[1] This provides surgical trainees with a safe and immersive platform to improve their skills.[2] Simulation-based training encompasses various modalities, including virtual reality, computer-based and anatomical models (e.g. three-dimensional (3D) models), cadaveric simulators, box trainers and robot-assisted surgical simulators.[3] Simulation training provides many benefits, including risk mitigation, ability to provide repetition, immediate and objective feedback, transferability of skills to other areas of surgery and a standardised method of training for all trainees.[4]

Otolaryngology has always been a highly specialised field that requires aptitude in various surgical methods, for example endoscopic surgery, open surgery and microsurgery. In the subspecialised area of rhinology there are many barriers to training that leave trainees feeling less experienced and potentially under confident.[5,6] For example, the complexity of rhinological procedures requires a high level of precision and anatomical knowledge, and therefore senior trainers may be hesitant to allow trainees to perform procedures independently without prior training. In addition, with increasing constraints on operating theatre space and availability of theatre staff, the National Health Service is seeing fewer rhinology index procedures being listed, for example septorhinoplasty, and therefore there are fewer training opportunities.[7] As an adjunct to this, system pressures are leading to limited time on surgical cases and therefore if a trainee is operating, efficiency and proficiency in these procedures is essential to keep lists running smoothly.[8]

As simulation models and techniques grow in their popularity, and new models are frequently being introduced, it becomes imperative to assess the effectiveness and validity of these training tools. In 2017, Musbahi *et al.* reviewed the current status of simulation in otolaryngology and found there was a limited number of high-validity otolaryngology simulators.[9] This systematic review aims to provide an up-to-date assessment of literature specifically focusing on validated rhinology simulators and their impact on trainees in otolaryngology.

Methods

Search strategy

PubMed, Embase, Cochrane and Google scholar (first 10 pages) were searched for studies conducted between July 2012 and July 2022. Search terms using Boolean

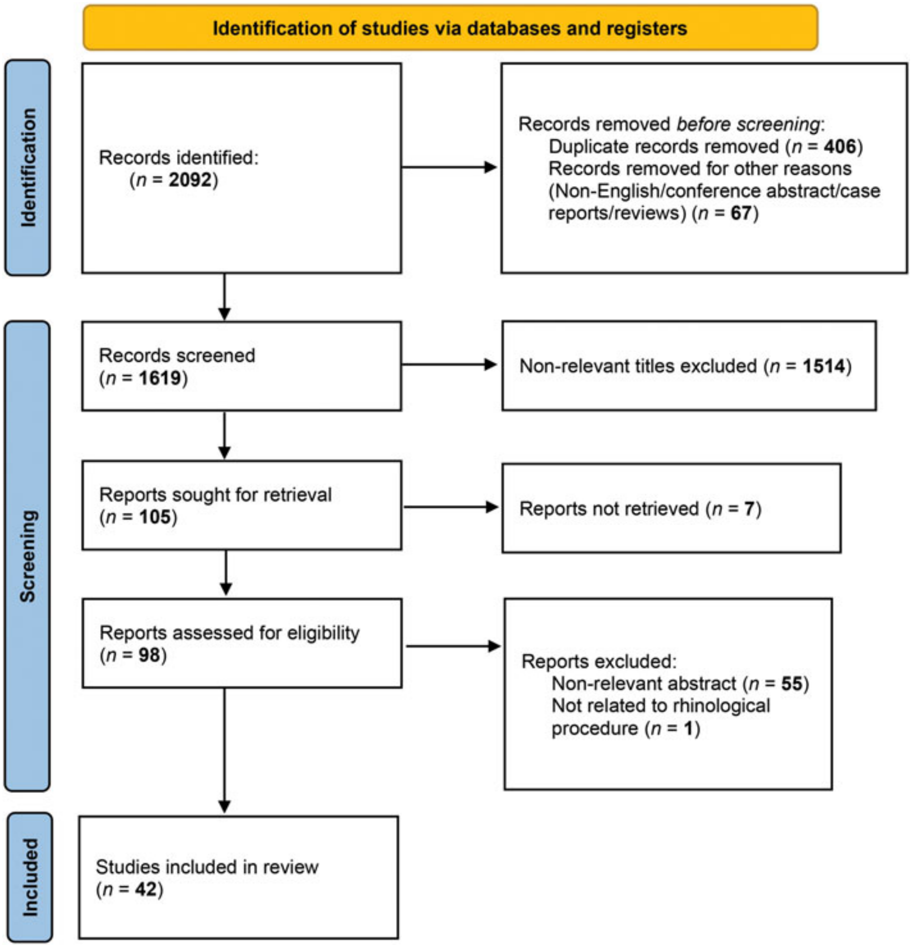

Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis ('PRISMA') flowchart of identification of eligible studies.

operators included 'ENT OR Otolaryngology OR Rhinology OR Nose' AND 'Simulation OR Simulator'. A total of 2092 articles were generated in our initial search. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis ('PRISMA') protocol (Figure 1) was used to deduce the final list of articles for review. Duplicates and non-English papers were excluded first. Titles and abstracts were then reviewed for relevance.

Selection criteria

Table 1 lists the inclusion and exclusion criteria.

Two independent reviewers sought references to establish studies that met the inclusion criteria to reduce the risk of bias. Subsequently, the PRISMA protocol was used to finalise a list of studies (see Figure 1).

Table 1. Study inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
English language	Non-English language and duplicates
Article relates to simulation in rhinological procedures (including facial plastics)	Review articles, case reports, conference abstracts
Article discusses simulation models to train residents and trainees and medical students	Article relates to simulation techniques in other otolaryngology or surgical procedures

Analysis and validity

The studies to be included were analysed for outcomes including procedure simulated, types of simulators used, participant outcomes from use of the simulation model, whether validity testing was used and level of fidelity. A level of evidence and a level of recommendation using the Oxford Centre of Evidenced-based Medicine classification, adapted for education, were given to each study that conducted validity testing.[10,11]

Results

In total, 2092 articles were identified using the search criteria. Of those, 42 met the inclusion criteria and were included in the review (see Figure 1).

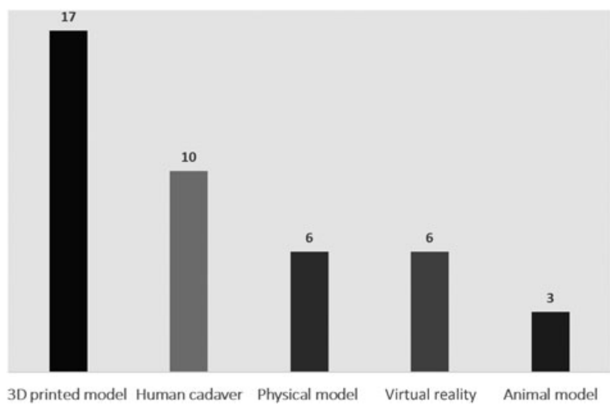

Figure 2. Types of simulators used in the articles included in the study.

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Within these 42 articles, 6 main types of simulator were described (see Figure 2): cadaveric human, 3D printed model, virtual reality and augmented reality, animal models and physical models. There was overlap as some articles reviewed more than one simulator or procedure. Twenty-six simulation studies had conducted at least one validation study.

The most simulated procedure was endoscopic sinus surgery ($n = 30$), followed by skull base and cerebrospinal fluid (CSF) leak repair ($n = 12$) and management of epistaxis and sphenopalatine artery ligation ($n = 7$). Septoplasty and septorhinoplasty were also covered ($n = 5$) (see Figure 3).

Endoscopic sinus surgery

A total of 30 studies described the use of an endoscopic sinus surgery simulator. The most commonly tested simulators were 3D printed models ($n = 12$),[12–23] followed by physical models ($n = 4$),[24–27] virtual reality and augmented reality ($n = 6$)[20,21,28–31] and cadaveric models ($n = 5$).[32–36] Animal models were tested in three studies.[37–39] Eleven studies performed validity testing for endoscopic sinus surgery simulators,[12–19,22,25,28,31,38] and of these the most common type of validity testing was face, content and construct validity. All studies that performed validity testing (see Table 2) found that their model had confirmation of validity.

All studies asked participants to complete tasks relating to basic functional endoscopic sinus surgery (FESS) (identification of anatomy, examination under anaesthesia, middle meatal antrostomy and ethmoidectomy). The exception being of one study which used virtual reality technology (CardinalSim) to simulate more complex procedures, for example an endoscopic endonasal approach to an inverted papilloma of the maxillary sinus.[29] Most 3D and virtual reality models demonstrated medium or high fidelity ($n = 13$) and four out of five virtual reality simulators used haptic devices for tactile feedback.[20,28–30] Virtual reality was the most costly simulation method, with the most expensive set up costing US$15 000.[28]

Finally, all studies showed that their simulation method improved outcomes amongst trainees. The levels of trainee tested amongst the studies included medical students ($n = 5$), interns ($n = 2$), junior residents and registrars ($n = 8$), senior residents and registrars ($n = 14$), and fellows and consultants and attending ($n = 15$). When consultants and attendings were included in studies, this was primarily used to assess validity. Most studies compared either a control group and a simulator group, or a before and after simulation measure of performance (e.g. the time to complete the task and dexterity and instrument handling). Most studies also asked for survey feedback from participants following their participation. All simulators for endoscopic sinus surgery showed either an improvement in measured outcomes following simulation or positive survey feedback.

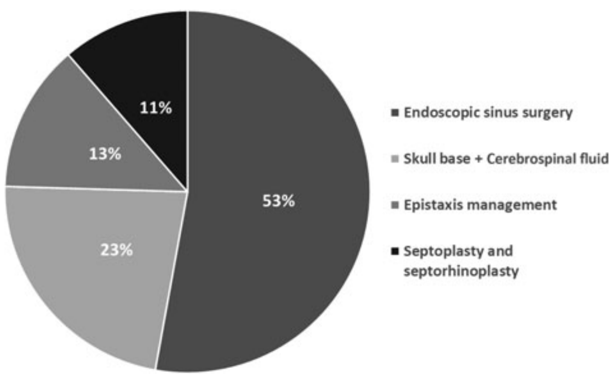

Figure 3. Distribution of skills simulated in the articles included in the study.

Skull base

Twelve studies looked at the use of simulation in training for skull base surgery. Of these studies, 42 per cent ($n = 5$) performed validity testing,[38,40–43] with face and content validity being the most tested. All six of these studies confirmed their models had validity. Three-dimensional printed models ($n = 4$)[22,42–44] and human cadaver models ($n = 4$)[40,41,45,46] were the most common simulators used. Animal models ($n = 2$)[38,39] and virtual reality and augmented reality ($n = 2$)[29,30] were also tested.

The most popular skills covered by the skull base simulation models included CSF leak and skull base repair ($n = 4$),[38–40,46] skeletisation of the internal carotid arteries ($n = 2$)[41,44] and sella turcica ($n = 2$).[43,44] Models to simulate CSF leak and skull base repair were only performed on either a human cadaver or an animal model. Both human cadaver models were created by AlQahtani *et al.*,[40,46] with an intradural catheter with fluorescein dye used to simulate CSF leak. Their initial study in 2018 did not validate the use of fluroscein dye, but in 2021 they performed validation studies using a five-point Likert scale questionnaire, a global rating scale of operative performance and a specific skull base reconstruction checklist to confirm the face, content and construct validity of their model. Other skills covered included management of an internal carotid artery injury using a human cadaver model[41] and clivus ablation, transpterygoid and transclival approaches using 3D printed models. Similar to the FESS simulation studies, all studies testing 3D models and virtual reality simulation used haptic feedback to improve participant experience and assessment.

All studies apart from AlQahtani *et al.*, Chan *et al.* and Won *et al.*[22,29,46] appraised their simulation models using either neurosurgical or otolaryngology trainees. Consultants were mostly included for validity testing. Most studies carried out post-simulation surveys that showed that the participants found models to be anatomically similar to real life and useful for their training in skull base surgery.

Epistaxis management

Seven studies simulated epistaxis management, of which 57 per cent (4 out of 7 studies)[13,14,19,38] performed validity testing. Face, content and construct were the most common validity tests. Three-dimensional printed models were the most commonly used (43 per cent),[13,14,19] followed by animal models (29 per cent),[38,39] human cadavers (14 per cent)[47] and physical models (14 per cent).[48]

Only one paper focused primarily on simulating epistaxis management,[13] with all other studies incorporating it into their review of other tasks. Three studies used simulation to allow candidates to practice sphenopalatine artery ligation[19,38,39] and four studies looked at the non-surgical management of epistaxis, for example nasal packing.[13,14,47,48] Gillanders *et al.* were the only group to use the PHACON sinonasal simulator (Phacon GmbH, Leipzig, Germany).[19] This is a 3D printed model used primarily to mimic endoscopic sinus surgery. In this study, authors commented on its use for simulating sphenopalatine artery ligation, but trainees felt that simulated bleeding was required to improve its

Table 2. Summary of studies conducting validity testing, including the level of fidelity, level of evidence (LoE) and level of recommendation (LoR) based on the Oxford Centre of Evidenced-based Medicine classification[10]

Type of model	Type of validation	Study	Year published	Fidelity	Outcome of validation	LoE	LoR
Endoscopic sinus surgery							
3D printed model	Face Content	Chang *et al.*[12]	2017	Medium	Y Y	3	4
Virtual reality	Face Educational Content	Dharmawardana *et al.*[28]	2015	Medium and high	Y Y Y	3	4
Animal model	Face Content	Awad *et al.*[38]	2014	n/a	Y Y	3	4
3D printed model	Face Content Construct	Bright *et al.*[13]	2021	Low	Y Y Y	3	4
3D printed model	Face Content	Zhuo *et al.*[14]	2019	High	Y Y	3	4
3D printed model (PHACON sinus simulator)	Face Content Construct Concurrent	Alwani *et al.*[15]	2020	High	Y Y Y Y	3	4
3D printed model	Construct	Yoshiyasu *et al.*[16]	2019	Medium	Y	3	4
Virtual reality	Face Content Convergent Discriminant Predictive	Fried *et al.*[31]	2010	Medium	Y Y Y Y Y	2	3
Physical model	Face Content Construct	Harbison *et al.*[25]	2017	Low	Y Y Y	3	4
3D printed model (McGill simulator)	Face Content	Varshney *et al.*[17]	2014	High	Y Y	3	4
3D printed model	Face Content Construct	Suzuki *et al.*[18]	2022	Medium	Y Y Y	2	3
3D printed model (PHACON sinus simulator)	Content Construct	Gillanders *et al.*[19]	2023	High	Y Y	3	4
Skull base							
Human cadaver	Face Content Construct	AlQahtani *et al.*[40]	2021	n/a	Y Y Y	3	4
Human cadaver	Face Content Construct	Shen *et al.*[41]	2017	High	Y Y Y	3	4
3D printed model	Face	Hsieh *et al.*[42]	2018	High	Y	3	4
3D printed model	Content	Tai *et al.*[43]	2016	High	Y	3	4
Animal model	Face Content	Awad *et al.*[38]	2014	n/a	Y Y	3	4
Epistaxis management							
Animal model	Face Content	Awad *et al.*[38]	2014	n/a	Y Y	3	4
3D printed model	Face Content Construct	Bright *et al.*[13]	2021	Low	Y Y Y	3	4
3D printed model	Face Content	Zhuo *et al.*[14]	2019	High	Y Y	3	4
3D printed model (PHACON sinus simulator)	Content Construct	Gillanders *et al.*[19]	2023	High	Y Y	3	4
Septoplasty and septorhinoplasty							
Physical model	Face Construct Concurrent	Rosenbaum *et al.*[50]	2022	n/a	Y Y Y	3	4

(*Continued*)

Table 2. (*Continued.*)

Type of model	Type of validation	Study	Year published	Fidelity	Outcome of validation	LoE	LoR
3D printed model	Face Content	AlReefi *et al.*[49]	2016	n/a	Y Y	3	4
Animal model	Face Content	Awad *et al.*[38]	2014	n/a	Y Y	3	4
3D printed model (PHACON sinus simulator)	Content Construct	Gillanders *et al.*[19]	2023	High	Y Y	3	4

3D = three-dimensional; n/a = the study did not comment; Y = Yes

likeness to reality. The trainees felt studies using animal models to simulate sphenopalatine artery ligation offered better anatomical similarities.

All studies found that participants were more confident in managing epistaxis following the use of their stimulator, although training for non-surgical management of epistaxis was understandably more beneficial for training medical students and junior trainees.

Septoplasty and septorhinoplasty

Septoplasty simulation was reviewed in five studies and septorhinoplasty in one. Animal models were used to simulate septoplasty in two studies,[38,39] two studies used 3D printed models[19,49] and one used a physical model.[50] A 3D printed model was also used in the study aiming to simulate septorhinoplasty.[51] All but one study for septoplasty performed validation studies, but the septorhinoplasty study did not test the validity of the model.

Two articles looked at septoplasty simulation alone,[49,50] whereas three studies looked at septoplasty in combination with other procedures. The study by AlReefi *et al.* claimed to be the first to create and validate a septoplasty training model.[49] This study used a 3D printed model and compared performance between professionals, senior residents and junior residents to validate the model. In a post-simulation questionnaire all participants agreed that the model was realistic. In 2022, a physical model was created by Rosenbaum *et al.* which used pigs' ears and a wooden frame.[50] The study was validated and 100 per cent of participants said they found it useful for their training.

Ho *et al.* created a low-cost 3D printed model to help trainees perform nasal osteotomy as part of a septorhinoplasty procedure,[51] and claimed it to be the first of its kind. Professionals tested the model and found it was useful, but no validation studies were performed.

Discussion

Simulation-based training in rhinology has escalated in the past five years to become an approach to address the challenges in training faced by otolaryngology trainees.[50] This systematic review aimed to provide an up-to-date assessment of the effectiveness and validity of various simulation models in enhancing the skills and confidence of rhinology trainees.

Since the review conducted by Musbahi *et al.* in 2017, there has been a significant increase in the number of simulation models being employed to train otolaryngology trainees in rhinology.[9] This has been especially apparent since the coronavirus disease 2019 pandemic. As shown by this review, nearly 50 per cent ($n = 20$) of studies[13–16, 18–20, 23–24,27,30,32,34–35,37,40,44,47, 50–51] were published in or after 2019 and many comment on the need for improved access to out-of-theatre training. These models encompass 3D printed models, virtual reality systems, physical models, human cadavers and animal models. Three-dimensional printed models were the most validated and were found to offer a cost-effective, medium to high fidelity option to rhinology simulation. Virtual reality systems, whilst expensive, provided a highly immersive and interactive learning environment.

Simulation training in the studies reviewed proved to be beneficial to all the trainees tested. Trainees found that simulation-based training demonstrated improved skills and increased confidence, as evidenced by reduced task completion times, enhanced dexterity and high survey scores. One notable observation, however, is that many of the simulation models tended to favour junior trainees. Most studies tested simulation models that focused on simpler procedures and pathologies, for example basic FESS or epistaxis management. More experienced clinicians commented that they would benefit from simulation of more complex surgical procedures.

Simulation-based training appears to be a valuable complement to traditional methods of training such as observation and hands-on experience. Its advantages include a controlled learning environment, risk mitigation and immediate feedback.[4] However, the synergy between both simulation and traditional methods should be further explored to optimise the training curriculum for otolaryngology trainees. Further studies are therefore needed to investigate long-term skill retention, patient outcomes and the impact of simulation on surgical proficiency.

There could be significant expense to enhancing surgical training with simulation. As the availability of better simulation models is increasing, the cost of simulation models will most likely decrease. Hence, as financial constraints continue to impact our healthcare systems, education departments will begin to look for economically viable and well-tested models, factors which are essential for their widespread adoption in training programmes.[52]

- Simulation-based training has become increasingly popular over the past 10 years but is still in the early stages of development and assessment
- Both high- and low-fidelity, as well as high- and low-cost, models have been found to enhance trainees' surgical competency and confidence in rhinology-based procedures
- There are currently no systematic reviews available assessing the impact of simulation-based training in rhinology
- Simulation-based training is important in rhinology because we are seeing a reduction in overall training opportunities
- Selection of an appropriate simulation model, coupled with rigorous validation and cost-effectiveness studies, is needed to ensure the integration of simulation-based training into training programmes

This review has several limitations, including the variation in the quality of evidence because it encompasses studies with different methodologies and levels of accuracy. In addition, the scope of this review may be limited by studies that were not highlighted with our search methods, and there may be further studies missed by restricting our search to only English language studies and those conducted within the last decade. Finally, it is challenging to eliminate the potential bias created by these studies, for example most articles were written by simulation creators with a potential vested interest or by clinicians with little to no previous simulation experience.

Conclusion

Improved training through simulation models may lead to more confident and proficient rhinology trainees, ultimately benefiting patient care. Simulation-based training is undoubtedly becoming more established with advancing technology and availability of resources.[53] As a result, we hope to see reduced risk to patients, increased efficiency and better management of rhinology pathologies. However, appropriate simulation models, coupled with rigorous validation and cost-effectiveness studies, are needed to ensure their integration into training programmes.

Competing interests. None declared

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