


BMJ Open Use of 3D printed head and neck models for simulating 10 common ENT emergency procedures: a prospective validation study

Umar Rehman ¹, Dermot Colton,² Sanjeev Gupta,³ Praneta Kulloo,⁴ Ananth Vijendren,⁵ James Howard,⁶ Purnima Sangwan,⁷ Cameron Davies-Husband,⁸ James Rudd,⁹ Max Whittaker,⁷ Kate Stephenson,¹⁰ Claudia Taylor,¹¹ Phoebe Roche,¹¹ Nicholas Eynon-Lewis,¹² Yogesh Bajaj,¹² Andrew Lau,¹³ Saleh Okhovat,¹⁴ Matt Rollin,¹⁵ Matt Lechner¹

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For numbered affiliations see end of article.

Correspondence to

Dr Matt Lechner;
m.lechner@ucl.ac.uk

ABSTRACT

Objective This study aims to validate a high-fidelity three-dimensional (3D)-printed head and neck model for training emergency medicine (EM) physicians, primary care physicians and allied health professionals in managing 10 common ear, nose and throat (ENT) emergencies.

Setting The study was conducted at an ENT Emergencies course in London.

Study design Prospective validation study.

Participants All delegates (n=90) were healthcare professionals. Among them, 60% (n=54) were EM residents/trainees, 28% (n=25) were primary care residents/trainees, 4% (n=4) were ENT residents/trainees, 4% (n=4) were emergency nurse practitioners, 2% (n=2) were primary care attending physicians and 1% (n=1) was an EM attending/consultant. All faculty were consultant ENT surgeons (n=11).

Intervention The 3D models, produced using proprietary 3D printing technology (Fuesetec), were used in a 1-day ENT emergencies course for validating training and confidence of delegates in performing 10 common ENT emergencies.

Results A total of 86% (n=77) of delegates found the models extremely or very helpful in learning ENT emergencies. Delegates rated the resemblance to real patients as excellent or very good in both haptic feedback (n=58, 64%) and tissue texture (n=67, 74%). Additionally, 74%–96% of delegates felt confident in performing the 10 ENT procedures after using the models.

Conclusions The 3D models enhanced participant confidence in performing 10 common ENT emergency procedures, demonstrating good face, content and indirect criterion validity. These models could support emergency ENT skill development in local emergency departments.

INTRODUCTION

Ear, nose and throat (ENT) disorders are common reasons for seeking care in the emergency department (ED) or via primary care.^{1,2} There is seen to be a lack of undergraduate and postgraduate teaching and training in

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ A diverse set of ear, nose and throat emergencies was represented, providing comprehensive training exposure.
- ⇒ The authors used face validity to assess the model's physical realism, gathering direct feedback from participants on its suitability for simulating procedural training scenarios. Content and indirect criterion validity ensured the model's alignment with postgraduate training curricula and its impact on self-reported confidence.
- ⇒ Validation measures did not include objective performance assessments of procedural skills after training.

ENT emergencies, resulting in newly qualified doctors not feeling adequately prepared to practice ENT.^{3–5} A study by Sharma *et al* found that 75% of junior doctors have not received sufficient ENT teaching to deal with common ENT emergencies, with 42% of junior doctors not feeling confident in managing common ENT emergencies.⁵ It has also been reported that 88% of senior ENT doctors on call are non-resident, which places more onus on junior doctors and the emergency medicine (EM) team to manage common ENT emergencies.³

Simulation training helps to mitigate patient safety risks by allowing individuals to practice procedures in a safe space without jeopardising patient safety.^{6,7} Simulation is an increasingly valuable tool in emergency education, with simulation-based training shown to aid in the acquisition of clinical skills more effectively compared with traditional lectures or tutorials.⁷ The increased demand for high-quality, cost-effective medical simulation

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has led to the incorporation of three-dimensional (3D) printed models to aid in simulation training.⁸

Previous studies have employed 3D models, and these have received positive feedback from trainees regarding common emergencies including: tracheostomy tube placement, peritonsillar abscess drainage and nasal packing.^{8–10} However, these studies typically use models that simulate only a particular emergency skill and so are not appropriate to teach the full breadth of ENT emergencies.⁸ Furthermore, the models reported within the literature have not been used beyond initial pilot testing, with no model currently being utilised or validated in clinical courses or teaching.^{8–10} ENT emergency procedures can be taught on cadavers or animal specimens, but these convey significant financial costs and reduced accessibility.⁸ Cadaveric and animal models are also limited in their ability to simulate pathological conditions. While procedures such as tracheostomy can be taught using these models, skills like quinsy drainage or otitis externa management are challenging to replicate. Therefore, there is a need for a high-fidelity training model that provides realistic anatomy, haptic feedback and tissue texture comparable to real patients—without the risks to patient safety or the high costs associated with cadaveric models—while encompassing a broad range of ENT emergencies in a single platform.^{8–10}

This study sets out to develop and validate a high-fidelity head and neck model, printed using proprietary 3D printing technology, which can be used to train EM physicians, primary care physicians and allied health professionals in 10 common ENT emergencies.

METHODOLOGY

3D-printed simulation model design

The head and neck models were created using ZBrush (Pixologic, California, USA). This digital sculpting software was used to recreate human anatomy by sculpting basic shapes. The individual anatomical components were then assembled and further edited on Netfabb (Autodesk, California) for manufacturing (figure 1A,B). The peritonsillar abscess was developed as a variation of the model created using the method above. Files were sculpted to include a peritonsillar abscess on Blender (Blender Foundation, Netherlands) and then printed in place of regular tonsils (figure 1B). The otology aspect was created using a combination of the above two methods (figure 1C). Ear CT scans were segmented using Mimics (Materialise NV, Belgium). Files that were not clear in scans were digitally sculpted in ZBrush and fitted into the model. Models were printed using the Stratasys Digital Anatomical Printer (Stratasys, Minnesota, USA). A combination of preset and custom digital materials was used to construct the model's various components. The models can be seen in figure 2A–C, as well as in online supplemental appendix 1A, with endoscopic appearances shown in online supplemental appendix 1B.

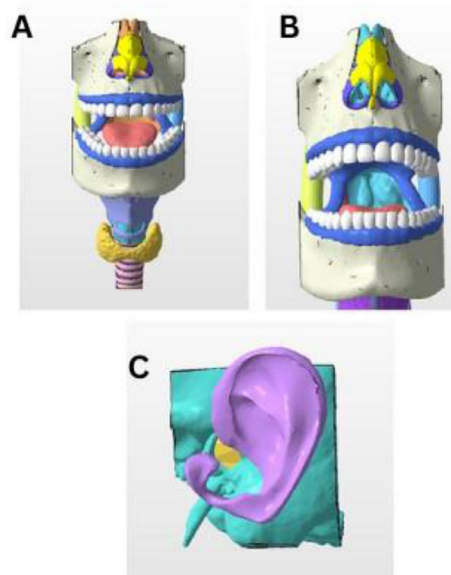


Figure 1 ENT emergency head and neck simulation models internal anatomy reconstruction. (A) Head and neck model. (B) Left-sided peritonsillar abscess model. (C) Narrowed external auditory canal for otitis externa simulation. The internal anatomy is displayed on segmentation software Netfabb (Autodesk). ENT, ear, nose and throat.

ENT emergencies training course

The models were subsequently validated in an ENT emergencies training course using a prospective validation study. Delegates attended an in-person course on managing 10 common ENT emergencies. The 10 ENT emergencies included foreign body nose removal, epistaxis management, peritonsillar abscess drainage, flexible nasendoscopy for stridor assessment, post-tonsillectomy bleed management, foreign body removal from the throat, Pope otowick insertion/otitis externa management, foreign body removal from the ear, tracheostomy insertion and drainage of a post-thyroidectomy haematoma.

This was a 1-day course consisting of small group lectures and practical skills sessions using 3D printed head and neck models. The faculty consisted of ENT consultants/attending surgeons, with a faculty-to-delegate ratio of 1:5 to aid in procedural steps and teaching. 3D model simulation training was delivered after delegates had received tutorials on common ENT emergencies and their management. Delegates rotated through 10 simulated stations, each starting with a case study of a common emergency presentation related to the skill being practised. They then spent 30 min using the models to practice each emergency procedure under the guidance of ENT consultant surgeons, rotating through each emergency. The equipment provided for each skill mirrored what is typically available in an emergency department, including headlights, tongue depressors, scalpels, syringes, needles, ribbon gauze and cautery sticks. Additional specialised equipment included microscopes for the otitis externa management, Pope otowick

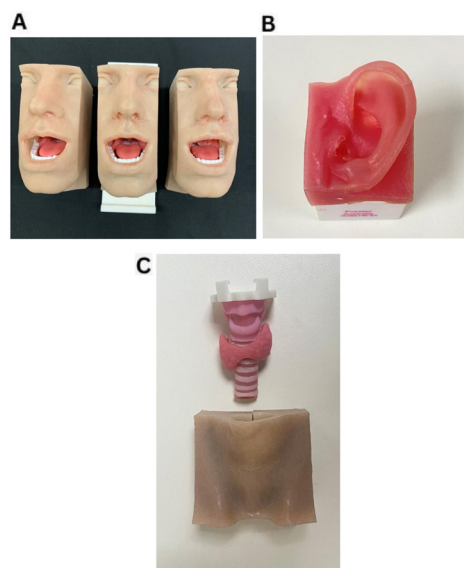


Figure 2 ENT emergency simulation models external display. (A) Head and neck model for simulating foreign body nose removal, epistaxis management, peritonsillar abscess drainage, flexible nasendoscopy, post-tonsillectomy bleed management and foreign body of the throat removal. (B) Ear model for simulating Pope otowick insertion/otitis externa treatment and foreign body ear removal. (C) 3D printed trachea and overlying neck for simulating tracheostomy insertion and drainage of a post-thyroidectomy haematoma. 3D, three dimensions; ENT, ear, nose and throat.

and foreign body ear stations, as well as flexible nasendoscopy for stridor assessment. Following the completion of the course, delegates were asked to complete paper surveys, which adopted a combination of yes/no items and Likert scales to evaluate their experience with the 3D models. All delegates provided informed consent to have their data used as part of a research study for the validation of the 3D models.

Validation

The validation of the 3D models involved a combination of methods. First, face validity was assessed by having delegates evaluate the realism of the models for performing ENT emergency procedures. Second, content validity was ensured through mapping the ENT procedures included to the postgraduate primary care and EM curricula.^{11 12} Moreover, content validity was further assessed by having ENT consultants rate the realism of the models specifically for performing common ENT emergency procedures. Lastly, indirect criterion validity was determined by assessing self-reported confidence of delegates in performing ENT emergency procedures after using the 3D models.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Breakdown of survey responses

A total of 90 delegates and 11 ENT consultant/attending surgeons used the 3D printed models for ENT emergency skills training and responded to the survey. Among them, 60% (n=54) were EM residents/trainees, 28% (n=25) were primary care residents/trainees, 4% (n=4) were ENT residents/trainees, 4% (n=4) were emergency nurse practitioners, 2% (n=2) was a primary care attending physician and 1% (n=1) was an EM attending/consultant. Prior experience in common ENT emergencies was assessed for 90 of the delegates (excluding ENT consultant/attending surgeons), which is displayed in online supplemental appendix 3.

Current teaching in ENT emergencies

Delegates (n=90) were asked about their current teaching on ENT Emergency procedures they receive within their department. No teaching was received by 58% (n=52) of delegates, while 26% (n=23) received lecture-based teaching, 12% (n=11) received small-group teaching and 4% (n=4) received teaching on real patients. None of the delegates had used 3D models within their local department teaching.

Face validity: realism of models for delegates

Face validity was assessed by asking delegates to rate the realism of the models, as displayed in table 1. Results indicated good face validity, with 70%–98% (range: 35–49) of delegates rating the realism as very good/excellent.

The overall realism of the model, including its visual appearance, internal/external anatomy and simulation of procedures, was reported using a 5-point scale: excellent, above average, average, below average or poor. Delegates rated the models as ‘excellent’ or ‘very good’ for performing the 10 emergency procedures: flexible nasendoscopy to assess for stridor (n=77, 86%), assessing and removing nasal foreign bodies (n=77, 86%), assessing and removing foreign bodies from the ear (n=81, 90%), managing otitis externa with Pope otowick insertion (n=83, 92%), assessment and management of a peritonsillar abscess using needle aspiration (n=68, 76%), assessing for and removing a foreign body from the throat (n=74, 82%), performing a tracheostomy (n=63, 70%), managing a post-thyroidectomy haematoma (n=72, 80%), managing epistaxis using cautery and nasal packing (n=68, 76%) and managing a post-tonsillectomy bleed (n=77, 86%). The full results depicting the delegate-reported realism of the models can be seen in table 1.

Delegates were asked to rate the realism (5-point scale: excellent, above average, average, below average or poor) of the haptic/tactile feedback provided by the models compared with real patient tissue. This encompassed the perception of pressure, vibration and resistance when performing the procedures and comparing these to what one might expect in a real patient. Most delegates rated this as excellent or very good (n=58, 64%), followed by

Table 1 Realism rating of the 3D models course delegates

Please rate the realism of the 3D models for each of the following procedures and assessment in comparison to real patients or cadavers	Excellent	Above average	Average	Below average	Poor	N/A
Assessment of stridor and performing flexible nasendoscopy	43 (48%)	34 (38%)	9 (10%)	2 (2%)	0 (0%)	2 (2%)
Assessing for and removing a foreign body of the nose	36 (40%)	41 (46%)	11 (12%)	0 (0%)	0 (0%)	2 (2%)
Assessing for and removing a foreign body of the ear	52 (58%)	29 (32%)	9 (10%)	0 (0%)	0 (0%)	0 (0%)
Managing otitis externa with the insertion of a Pope otowick	40 (44%)	43 (48%)	7 (8%)	0 (0%)	0 (0%)	0 (0%)
Managing a peritonsillar abscess with needle aspiration	34 (38%)	34 (38%)	18 (20%)	2 (2%)	2 (2%)	0 (0%)
Assessing for and removing a foreign body of the throat	40 (44%)	34 (38%)	9 (10%)	4 (4%)	1 (1%)	2 (4%)
Performing a tracheostomy*	40 (44%)	23 (26%)	0 (0%)	2 (2%)	0 (0%)	11 (12%)
Managing a post-thyroidectomy haematoma	40 (44%)	32 (36%)	9 (10%)	0 (0%)	0 (0%)	9 (10%)
Managing epistaxis including nasal packing and cautery	38 (42%)	31 (34%)	21 (23%)	0 (0%)	0 (0%)	0 (0%)
Managing a post-tonsillectomy bleed	36 (40%)	41 (46%)	4 (4%)	0 (0%)	0 (0%)	9 (10%)

*14 delegates did not complete this question.
3D, three dimensions; N/A, not available.

32% (n=29) rating them as average, and 4% (n=4) rating them as below average.

Furthermore, delegates and ENT consultants were asked to rate the realism (5-point scale: excellent, above average, average, below average or poor) of the tissue texture and handling compared with real patient tissue, which added to the content validity. This encompassed the firmness, elasticity and texture accuracy as compared with real tissue. Most delegates rated this as excellent or very good (n=67, 74%), with 24% (n=22) rating them as average and 1% (n=1) rating them as below average.

Content validity: ENT consultant surgeon ratings of realism of simulation

Content validity was ensured by mapping the procedures to the primary care and EM postgraduate curricula.^{11 12} This assurance was further fortified by incorporating 10 common ENT emergency procedures. This was following

discussions with ENT surgeons across the UK. This step ensured the relevance of the models and skills to those working in EM and primary care. Moreover, having consultant ENT surgeons rate the realism of using the models in simulating 10 common ENT procedures furthered the content validity. The full results depicting ENT consultant reported realism of the models can be seen in [table 2](#). Similar results between the ENT consultant surgeons and delegates were seen regarding the realism, which highlights good content validity.

ENT consultants were asked to rate the realism (5-point scale: excellent, above average, average, below average or poor) of the haptic/tactile feedback provided by the models compared with real patient tissue. All (n=11, 100%) ENT consultants rated the models to be excellent or very good for haptic/tactile feedback compared with real patient tissue.

Table 2 Realism rating of the 3D models course ENT consultants

Please rate the realism of the 3D models for each of the following procedures and assessment in comparison to real patients or cadavers	Excellent	Above average	Average	Below average	Poor	N/A
Assessment of stridor and performing flexible nasendoscopy	5 (46%)	6 (55%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Assessing for and removing a foreign body of the nose	11 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Assessing for and removing a foreign body of the ear	4 (36%)	5 (46%)	2 (18%)	0 (0%)	0 (0%)	0 (0%)
Managing otitis externa with the insertion of a Pope otowick	8 (73%)	2 (18%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)
Managing a peritonsillar abscess with needle aspiration	9 (82%)	1 (9%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)
Assessing for and removing a foreign body of the throat	10 (91%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Performing a tracheostomy	2 (18%)	3 (27%)	6 (55%)	0 (0%)	0 (0%)	0 (0%)
Managing a post-thyroidectomy haematoma	6 (55%)	3 (27%)	0 (0%)	1 (9%)	0 (0%)	0 (0%)
Managing epistaxis including nasal packing and cautery	2 (18%)	8 (73%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)
Managing a post-tonsillectomy bleed	1 (9%)	7 (64%)	3 (27%)	0 (0%)	0 (0%)	0 (0%)

3D, three dimensions; ENT, ear, nose and throat; N/A, not available.

Table 3 Delegate confidence in managing common ENT emergencies following the use of 3D models

To what extent do you agree with the following statements? Following the use of the 3D models on the course, I feel confident in:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Not performed
Assessing for and removing a foreign body of the ear	56 (62%)	25 (28%)	5 (6%)	2 (2%)	2 (2%)	0
Assessing and managing otitis externa including the insertion of a Pope otowick	54 (60%)	22 (24%)	9 (10%)	2 (2%)	3 (3%)	0 (0%)
Managing a peritonsillar abscess using needle aspiration	47 (52%)	20 (22%)	18 (20%)	4 (4%)	1 (1%)	0 (0%)
Assessing for and removing a foreign body of the throat	54 (60%)	20 (22%)	11 (12%)	0 (0%)	2 (2%)	3 (3%)
Performing a tracheostomy	52 (58%)	20 (22%)	0 (0%)	0 (0%)	7 (8%)	11 (12%)
Managing a post-tonsillectomy bleed	58 (64%)	14 (16%)	11 (12%)	0 (0%)	4 (4%)	3 (3%)
Managing a post-thyroidectomy haematoma	52 (58%)	29 (32%)	2 (2%)	5 (6%)	2 (2%)	0 (0%)
Managing epistaxis including nasal packing and cautery	65 (72%)	20 (22%)	4 (4%)	0 (0%)	1 (1%)	0 (0%)
Assessing for and removing a foreign body of the nose	61 (68%)	23 (26%)	2 (2%)	0 (0%)	2 (2%)	2 (2%)
Assessment of stridor and performing flexible nasendoscopy	38 (42%)	38 (42%)	11 (12%)	0 (0%)	2 (2%)	1 (1%)
3D, three dimensions; ENT, ear, nose and throat.						

Furthermore, ENT consultants were asked to rate the realism (5-point scale: excellent, above average, average, below average or poor) of the tissue texture and handling compared with real patient tissue. All (n=11, 100%) of the ENT consultants rated the tissue handling in comparison to real patient tissue as excellent/very good.

Criterion validity

Next, we analysed the indirect criterion validity by assessing delegates' self-reported confidence after using the 3D models. The confidence levels of delegates in practising common ENT emergencies are displayed in table 3 with most delegates (74%–96%) feeling confident in performing the 10 ENT emergency procedures following the use of the 3D models. Hence, demonstrating good indirect criterion validity.

Overall, 56% (n=28) of delegates found the models to be extremely helpful in enhancing their learning of ENT emergencies, with 30% (n=15) finding the models very helpful and 14% (n=7) finding the models moderately helpful to their learning. No respondents found the models slightly or not at all helpful.

Future directions

Overall, 90% (n=81) of delegates would recommend the use of 3D models to other trainees for learning ENT emergency procedural skills, similarly 100% (n=11) of ENT surgeons would recommend the use of 3D models to their trainees. Additionally, 80% (n=72) of respondents stated that they would prefer to have 3D models in future courses as their preferred method to practice ENT emergency skills, while 20% (n=18) of respondents would prefer to see a combination of 3D models together with cadavers.

Overall, for the delegates and ENT surgeons, 98% (n=99) of respondents felt that implementing the 3D

models into local ED/primary care settings would help improve trainee confidence in ENT emergency procedural skills, while only 2% (n=2) were unsure about this. Delegates were asked, "What would be the biggest factor in deciding whether to incorporate 3D models into your local department for learning ENT emergency skills?" In response, 62% (n=56) cited the availability of local faculty to assist in teaching, 31% (n=28) stated that cost/price of models would be a determining factor and 7% (n=6) mentioned that the longevity of the model would influence their decision.

DISCUSSION

Previous research has revealed that medical professionals often lack confidence in managing common ENT emergencies due to inadequate training and teaching.⁵

Within this study, most delegates rated the models as realistic for all 10 of the emergency procedures, which indicates good and consistent face validity. Additionally, a significant proportion of respondents rated the haptic/tactile feedback and tissue handling/texture resemblance from the models as excellent or very good. The utilisation of 3D models was associated with enhanced participant confidence in performing 10 common ENT emergency skills, thereby highlighting the study's good indirect criterion validity.

Improving competence and confidence of emergency care providers

Within our cohort, the 3D models were associated with increasing self-reported confidence by the delegates performing 10 common ENT emergency procedures. Given the specialised nature and often time-critical state of ENT emergencies, frontline staff, such as EM doctors

and primary care physicians, should undergo training to develop confidence in performing common ENT emergency procedures.^{3 5 7} A doctor's competency in procedural skills is paramount to patient safety, as evidenced by the increased mortality, morbidity and prolonged hospital stays associated with procedure-related complications.¹³ A previous study highlights that junior doctors working in ED are not confident in identifying and managing common ENT emergencies.¹⁴ Delayed treatment for these conditions can lead to significant patient safety concerns and potentially death. With many ENT departments having an out-of-hours service where first-line emergency cover is provided by a cross-over system shared by other specialties, the on-call doctor may have no previous ENT experience.^{3 14} Hence, there is a clear indication for front-line providers working in the ED and primary care to receive training in performing ENT emergency procedures, with 3D models offering a method to facilitate this training.

Incorporating 3D models into local departments

Adopting novel 3D head and neck models has been demonstrated to enhance confidence in performing common ENT emergency procedures following a 1-day course. These models were associated with good face, content and indirect criterion validity.

Overall, 98.4% of our respondents felt that the models should be used in local ED/primary care settings to improve trainee confidence in ENT emergency procedures, with the models being adaptable to simulate various ENT pathologies. The availability of locally skilled faculty to allow for training was the biggest deterring factor for incorporating the models into local departments. The availability of experienced faculty to oversee and facilitate procedural skills allows for immediate feedback, reflection and learning. This, in turn, enhances simulated skills learning.^{15 16} However, the presence of experienced faculty may not be always required. Previous research suggests that independent use of simulators in surgery and procedural skills, without expert feedback, may be advantageous and preferable to proctored simulation.¹⁷ The models do allow for repetitive practice and training among trainees, which can in turn speed up skill adoption.¹⁸

The 3D models have the added advantage for gaining experience in certain procedures, where the clinical case-load and exposure may be low. Having locally available 3D models would allow doctors to practise emergency ENT procedures regularly and, therefore, prevent skill-fade.

Future directions

Future research should compare the 3D model to existing training tools, such as cadaveric or animal models, where applicable. However, this may be challenging, as no single comparator method currently exists for all 10 ENT emergencies. Cadaveric and animal models cannot accurately replicate certain pathological states, such as quinsy or otitis externa. While procedures like tracheostomy can be

compared across 3D, cadaveric and animal models, these traditional methods are often associated with high costs and regulatory constraints. Future studies should incorporate objective skills assessments to evaluate precourse and postcourse performance improvements using 3D models. Additionally, including participants with varying levels of experience in ENT emergencies would help distinguish differences between novice and expert groups.

Limitations

This study had several limitations. First, each respondent had varied experience in ENT, which was not measured as part of the validation of the models. Second, ENT emergency procedure performance via an assessment of competence was not evaluated within this study; therefore, direct criterion validity was not measured. Third, the models were used in a non-validated training programme, and objective skill assessment scores were not measured precourse and postcourse. This could be an area for future research. Hence, the purpose was not to ensure that delegates were signed off and competent to deliver emergency care; rather, these 3D models were part of a course and are still in the evaluation stage. Finally, ENT experience/exposure was not measured beyond prior experience in performing the 10 procedures.

Author affiliations

¹UCL Division of Surgery & Interventional Science, London, UK

²City and Hackney Teaching Primary Care Trust, London, UK

³Sheffield Children's Hospital, Sheffield, UK

⁴University Hospital Lewisham, London, UK

⁵East and North Hertfordshire NHS Trust, Stevenage, UK

⁶Wrexham Maelor Hospital, Wrexham, UK

⁷Homerton Healthcare NHS Foundation Trust, London, UK

⁸Charing Cross Hospital, London, UK

⁹Royal Free London NHS Foundation Trust, London, UK

¹⁰Birmingham Children's Hospital NHS Foundation Trust, Birmingham, UK

¹¹Department of Head and Neck Surgery, Addenbrooke's Hospital, Cambridge, UK

¹²The Royal London Hospital, London, UK

¹³Manchester Royal Infirmary, Manchester, UK

¹⁴Glasgow Royal Infirmary, Glasgow, UK

¹⁵Imperial College Healthcare NHS Trust, London, UK

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Contributors UR conducted the data analysis, involved in study design and conception, manuscript preparation and editing. DC involved in study design and conception, manuscript preparation and review. SG, PK, AV, JH, PS, CD-H, JR, MW, KS, CT, PR, NE-L, YB, AL and SO involved in study design and conception and manuscript review and editing. MR and ML involved in data analysis, study design and conception, manuscript preparation, manuscript editing, manuscript review. ML is the guarantor and corresponding author of the manuscript.

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Competing interests ML is on the advisory board for the company Fusetec which provided the technology and Director of Innocrates. All other authors have no completing interest to declare.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Delegates taking part in the survey provided informed consent to participate in the study and have their data used as part of research by voluntarily completing the survey. All data collected was anonymous, and no patient data were collected or used as part of the qualitative research. In accordance with the ethical guidelines prevailing in the UK, an extensive ethical assessment was conducted using the UK Research and Innovation (UKRI) Research Ethics Tool prior to the initiation of our study. Ethical approval was not required as per the UKRI Research Ethics Tool (online supplemental appendix 2). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. The data that support the findings of this study are available from the corresponding author on reasonable request.

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ORCID iD

Umar Rehman <http://orcid.org/0000-0002-4856-3414>

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