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Original Article

Use of a Caprine Model for Simulation and Training of Endoscopic Ear surgery

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BACKGROUND: The objective of this study was to evaluate the utility of a caprine model in endoscopic ear surgical education using the index procedures of tympanoplasty and ossiculoplasty. Specifically, this study assessed the face and content validity of the caprine model, and the potential impact of anatomical differences on trainee understanding of human middle ear anatomy.

METHODS: Twelve otolaryngology trainees attended a 3-hour endoscopic ear surgery course utilizing the caprine model in which they completed canalplasty, tympanoplasty, and ossiculoplasty. Prior to the course, the trainees completed a self-reported needs assessment and knowledge assessment of human middle ear anatomy. Following the course, the trainees repeated the knowledge assessment and completed evaluation and validation questionnaires. Five-point Likert scores were used for the needs assessment and validation questionnaire.

RESULTS: Of the 12 trainees, 9 participated in the study. All domains of the learner needs assessment showed an average improvement of 1 point on the post-course evaluation with 6 of 9 domains being significantly improved using the Wilcoxon signed-rank test ($P < .05$). The model achieved validation in the domains of face, content, and global content validity with an average Likert score > 4. Knowledge assessment scores increased by 7% ($P = .23$) after the course compared to before.

CONCLUSION: The caprine model offers an effective surgical simulation model for endoscopic ear surgery training with good face and content validity. We find it to be readily available and affordable. We currently use it routinely to give otolaryngology residents the experience of endoscopic ear surgery before operating on patients.

KEYWORDS: Endoscopy, tympanoplasty, otologic surgical procedures, medical education

INTRODUCTION

Transcanal endoscopic ear surgery is an increasingly common surgical technique.[1,2] There is a very shallow learning curve and trainees have limited opportunities to hone their skills in the operating room. In contrast to traditional, microscope-guided ear surgery, which has a long history of training on human temporal bone models in skills labs, in-house surgical simulation for endoscopic ear surgery has not yet become established in residency training programs. Consequently, skills are learned in the operating room increasing procedure duration.[3] Further, newly graduated consultant otolaryngologists have identified otology and in particular ossiculoplasty as areas where they are less competent upon completion of residency training.[4] As such, the development and use of high-fidelity, economically viable training models is an important requirement for residency training.

Currently, the gold standard training model for endoscopic ear surgery is a fresh frozen cadaver head, though this can be prohibitively expensive and is not available in all jurisdictions. Multiple synthetic, virtual reality, and 3D-printed models are currently in existence.[5,6] Many of these were developed for use in teaching temporal bone drilling with a focus on the fidelity of drilling the hard bone. These are poorly adapted to endoscopic ear surgery training as it requires more emphasis on soft tissue dissection and handling. Synthetic models developed specifically for endoscopic ear surgery can offer accurate anatomy though, along with low-fidelity models, do not provide a realistic simulation of soft tissue handling which is an important component of transcanal surgery.[7,8]

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An ovine (sheep) model has been developed and used in endoscopic ear surgery education as an economically viable way of offering high-fidelity simulation of tissue similar to that of humans.[9,10,11,12] The favorable comparative anatomy has been described in detail.[13] Currently in our center, due to infection control and animal use practices, we are not able to use the ovine model. A caprine (goat) model has been explored for teaching 2-handed endoscopic ear surgery using an endoscope holder.[14] We propose that a fresh frozen caprine head would offer similar benefits to previously studied ovine models and provide an economically viable and useful teaching aid to learners. In assessing any novel surgical simulator, the domains of face and content validity must first be considered.[6] Face validity refers to the degree to which the simulation resembles the real-world situation. Content validity refers to how well the simulation captures all aspects of the content being taught. Previous research has questioned the external validity of animal models specifically as it relates to knowledge transfer of surgical anatomy,[9] but the single prior report on the feasibility of the caprine model suggests the comparative anatomy may be suitable.[14]

The objectives of the study were to evaluate (i) the utility of a caprine model in endoscopic ear surgical education using the index procedures of tympanoplasty and ossiculoplasty and (ii) the face and content validity of the caprine model, including an evaluation of the potential impact of anatomical differences on trainee understanding of human middle ear anatomy.

METHODS

Model Selection

Through literature review and consideration of logistics in our surgical skills lab, a fresh frozen goat head was selected as likely to provide a viable and readily available simulation model. A single goat head was obtained and an anatomic study was carried out through computed tomography (CT) scanning. A surgeon with 10 years of experience in transcanal endoscopic ear surgery performed the index procedures of endoscopic canalplasty, tympanoplasty, and ossiculoplasty on the caprine model to investigate whether it was a reasonable choice for an animal model. Independently, the procedures were repeated by a fellow on the contralateral ear, without supervision, to assess the model from an experienced trainee's perspective. The principle anatomical differences in the model are illustrated in Figure 1. In comparison with human anatomy, the curvature of the bony meatus obscures more of the pars tensa. Access can be improved by performing canalplasty. The body of the incus and malleus head lie medial to a relatively large pars flaccida and are not covered by a scutum. Ossicular morphology is fairly similar, but the long process of incus is comparatively short and does not extend medial to the chorda tympani nerve. Access to the ossicles, including the stapes footplate, is very suitable for ossiculoplasty. Both surgeons found that these anatomical differences were sufficiently minor that further evaluation of the face and content validity for residency training was considered appropriate. Approval to study resident evaluations of their experience with the model was obtained from the Research Ethics Board (REB# 1000076174).

Model Preparation

The specimens were received fresh from the supplier. The auricle had already been removed leaving exposed cartilaginous external auditory canal (EAC). There was often debris in the EAC that required microdebridement. The anatomy was generally well preserved between specimens and tissue characteristics were quite consistent, though 1 specimen had bilateral pars flaccida cholesteatoma with thickened middle ear mucosa.

Participants and Course Structure

Twelve otolaryngology surgical trainees were invited to participate in an endoscopic ear surgery simulation course which utilized the caprine model.

The course was structured as a 3-hour dissection course. Each trainee was asked to review an educational course pack prior to attending the course in order to maximize hands-on dissection time in the skills laboratory. The course pack consisted of a presentation reviewing human endoscopic ear anatomy; narrated instructional videos of canalplasty, tympanoplasty, and ossiculoplasty on both human subjects and the caprine model; and access to CT images of the goat temporal bone. Educational videos were developed utilizing the IVORY guidelines.[15]

The course was run twice with 6 trainees at a time and 2 staff facilitators with extensive experience in endoscopic ear surgery. Each

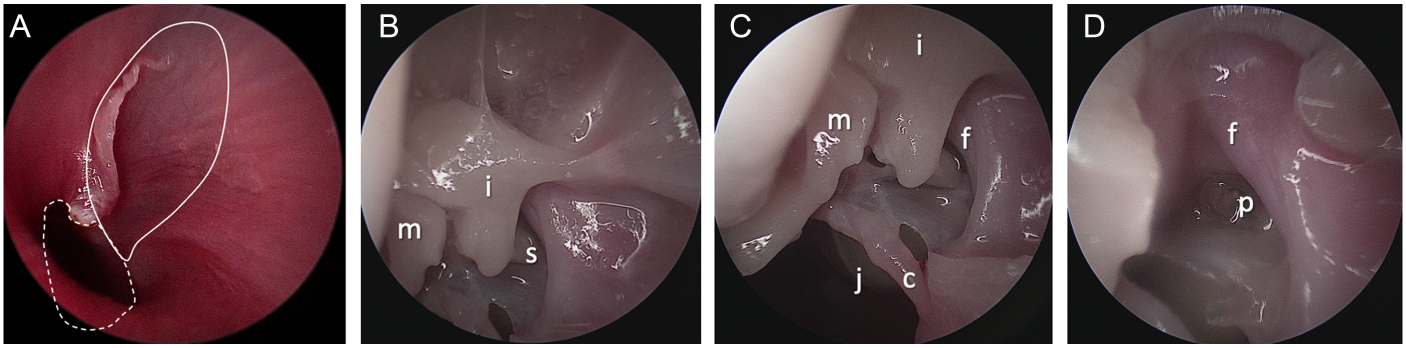

Figure 1. (A) Otoscopic image of the left caprine tympanic membrane. The approximate position of pars flaccida is indicated by solid white line and pars tensa by dashed white line. In comparison with human anatomy, the pars flaccida is relatively large and the pars tensa is partially obscured beyond the curvature of the bony meatus. (B) Middle ear after the elevation of the pars flaccida showing the position of the malleus (m), incus (i), and posterior crus of the stapes (s). The ossicular heads are not covered by scutum. (C) The facial nerve (f) can be seen posterior to the long process of the incus. An incomplete mucosal fold is present between the stapes and chorda tympani nerve (c). The Jacobsen nerve (j) can be seen crossing the promontory. (D) After removal of the incus and stapes superstructure there is a clear view of the facial nerve and stapes footplate (p).

trainee had access to 1 fresh frozen goat head (2 ears) obtained from a distributor at a cost of CAD$45 per head. Surgical equipment included a 0° and a 30°, 3 mm 14 cm endoscope (Spiggle and Theis, Overath, Germany) with a light source, camera, and monitor, with a set of Panetti endoscopic ear instruments (Spiggle and Theis, Overath, Germany) and high-speed drill with 2-mm curved diamond burr (Xomed Medtronic, Minneapolis, Minn, USA). A single piezoelectric bone removal device was also available for use (Piezosurgery, Mectron s.p.a., Carasco, Italy). Course participants had access to titanium partial and total ossiculoplasty replacement prostheses (ALTO, Grace Medical, Memphis, Tenn, USA) for ossiculoplasty and a porcine-derived grafting material (Biodesign, Cook Medical, Bloomington, Ind, USA) for tympanoplasty. Videos of the caprine model dissection were played for reference throughout the course.

The residents were led through a standard dissection with the goal of completing a canalplasty, tympanoplasty, and ossiculoplasty. If time was available, residents were then able to proceed with the same steps on the contralateral ear.

Model Evaluation

Prior to the distribution of the educational course pack described earlier, participants completed pre-course evaluations to evaluate their (i) knowledge of human middle ear anatomy (knowledge assessment) and (ii) self-reported assessment of their skill set in middle ear surgery and perceptions of their educational requirements for endoscopic ear surgery (learner reported needs assessment). These surveys were repeated after the course along with an additional validation survey. All surveys were conducted using Google forms and participants gave consent for use of their responses in this study. To protect resident confidentiality, all surveys were completed anonymously, but participants used a self-generated personal identification number to allow matched comparison of pre- and post-responses.

Knowledge Assessment

The evaluation of knowledge of middle ear anatomy was conducted to determine whether the use of the goat model disrupted residents' understanding of human anatomy. The assessment consisted of intra-operative endoscopic images from 5 human middle ears. Each image had 3 or 4 arrows identifying structures that the trainee was asked to identify in short answer format, in total there were 24 questions. The same images and questions were used pre- and post-course. Pre- and post-seminar scores were compared using the Wilcoxon signed-rank test.

Learner Reported Needs Assessment

Learner needs were reported on survey questions using a 5-point Likert scale with 1 representing "very weak" and 5 representing "very strong." Residents were asked to report their perception of their ability to perform surgical skills with either microscope or endoscope, including their ability to avoid complications of ossicular chain injury, facial nerve injury, or jugular bulb injury. The needs assessment was completed pre- and post-course to assess if needs were being met. Pre- and post-course evaluations were summarized using descriptive statistics[16] and compared with the Wilcoxon signed-rank test.

Validation Survey

Face, content, and global validity questions were prepared based on a review of similar studies within the otolaryngology education literature and answered using a 5-point Likert scale.[12,6,17] A median score of 4 or greater was considered validation for each specific question.

Table 1. Surgical Experience of Participants. Cases Refers to Any Ear Surgery Completed Using an Endoscope

	PGY-2 (n = 3)	PGY-3 (n = 2)	PGY-4 (n = 2)	PGY-5 (n = 2)	Total (n = 9)
Mean cases	0	1	7	21	7
Range	0	0-3	5-10	20-22	0-22

PGY, post-graduate year of training.

Statistical Analysis

Statistical analysis was run using 2-sided Wilcoxon rank tests with a significance level of $P < .05$ (SAS OnDemand for Academics, NC, USA).

RESULTS

Nine residents chose to participate in the course evaluation study. The year of training and experience of the residents that participated in the course is summarized in Table 1, showing an increase in endoscopic ear surgery experience later in residency.

All domains reported on the learner needs assessment, seen in Table 2, showed an average improvement of 1 point on the post-course evaluation. Junior learners tended to show a larger increase than senior learners. Six out of 9 domains improved significantly with a $P < .05$. The greatest need and improvement was found for ossiculoplasty.

The average score for the assessment of knowledge of human middle ear anatomy increased slightly after the course from 15.6/24 (65%, range 25%-92%) to 17.3/24 (72%, range 50%-96%), but this was not statistically significant ($P = .23$). As the number of trainees in each age group was small, subgroup analysis cannot be performed, but it was seen that the most senior trainees scored the highest marks, and the more junior trainees showed a greater improvement in score. Overall, on the 24-question knowledge assessment, 25% of answers changed from incorrect to correct after the course which would be consistent with an improvement in anatomical knowledge, 9% of answers changed from correct to incorrect, and 19% of answers remained incorrect before and after the course.

Validation scores, summarized in Table 3, were assessed on a 5-point Likert scale with 1 representing "strongly disagree" and 5 representing "strongly agree." A score of 4 or more was considered validation. There was validation for all domains. Importantly, participants did not report that the goat head anatomy confused their understanding of human anatomy.

DISCUSSION

This is the first study assessing the validity of a caprine model in endoscopic ear surgery education. The caprine model had a strong face, content, and global content validity. It did not erode learners' knowledge of human anatomy and offered subjective improvement in surgical skills. While the sample size was modest, the course and use of caprine model received extremely positive feedback from participants. Following this study, we have introduced simulation on the caprine model to our residency program: all residents currently

Table 2. Median Scores on the Learner Reported Needs Assessment and Mean Change from Pre-Course to Post-Course. Five-point Likert Scale with 1 Representing "Very Weak" and 5 Representing "Very Strong". *P* values: Wilcoxon Signed-Rank Test

	Pre-Course	Post-Course	Mean Change	*P*
1. My knowledge of endoscopic ear anatomy is	2	3	1	.12
2. My current endoscopic soft tissue dissection and handling skills are	2	3	1	.06
3. My comfort level with the surgical use of otologic endoscope and endoscopic instruments is	2	3	1	.02
4. My current understanding of the steps in an endoscopic tympanoplasty is	3	4	1	.01
5. My ability to raise a tympanomeatal flap (with endoscope or microscope) is	3	3	0	.12
6. My ability to drill a canalplasty is*	2	3	1	.02
7. My ability to position a tympanoplasty graft is*	2	3	1	.01
8. My ability to perform an ossiculoplasty is*	1	3	2	.01
9. My ability to prevent complications is*	2	3	1	.01

*Ability to perform surgical skills was with either microscope or endoscope
Complications listed in question 9 were: ossicular chain injury, facial nerve injury, jugular bulb injury.

complete a supervised training session prior to starting their clinical endoscopic ear surgery rotation. Our impression is that this has allowed trainees to learn the requisite skills more safely and quickly.

Simulation models commonly have limitations in face and content validity. The advantage of the caprine model is that it excels in the domain of content validity, providing accurate representation of soft tissue handling and surgical steps. The validation survey and our own observations are comparable with reports of the use of the ovine model in these domains as providing a suitable, cost-effective alternative to fresh-frozen human cadavers.[9,12] We consider the benefits of soft tissue handling in tympanomeatal flap elevation and tympanoplasty graft positioning to be superior to the use of 3D-printed models in this regard. When considering the important topics of animal welfare and sustainability, it is relevant to point out that the goat heads were obtained from surplus at a butcher's abattoir as they are not widely used as a food source and also that this model is biodegradable. In some jurisdictions, the caprine model may be more readily available than the ovine model.

With respect to face validity, the authors acknowledge that the caprine model inevitably has some limitations. However, a previous study has described the anatomical differences between goat and human from the perspective of endoscopic ear surgery and concluded that they were sufficiently small to make training on the caprine model feasible.[14] As such the goal of this study was to assess if the face validity was acceptable from a trainee's perspective and ensure that it did not confuse understanding of human anatomy. The most significant anatomical difference was that the ear canal of the goat was found to require a more significant canalplasty than a normal human ear canal. This did increase the time necessary to enter the middle ear but enabled the learners to gain more experience using a surgical drill alongside the endoscope which can be of value clinically when encountering narrow ear canals and for access in cholesteatoma surgery.

Before introducing the caprine model routinely into our surgical training program, we were concerned to check for any sign that anatomical differences might cause confusion in the understanding of human anatomy. Reassuringly, 25% of answers improved on the knowledge assessment whereas only 9% became worse. Errors were inconsistent: most of these errors occurred only once. That there was no pattern toward systematic error of several trainees giving the same worse answer, suggests that the model does not systematically mislead interpretation of anatomy. Further, learners reported that the goat head enhanced their understanding of human anatomy and did not confuse their understanding of human anatomy on post-course assessment. Our overall impression is that the caprine model did not

Table 3. Validation Questions. Five-Point Likert Scale with 1 Representing "Strongly Disagree" and 5 Representing "Strongly Agree"

Face validity	
Anatomy of the goat model is similar enough to a human that human anatomy knowledge can be applied	4
Use of the goat model enhanced my understanding of human anatomy	4
Use of the goat model confused my understanding of human anatomy	2
Content validity	
Performing tissue dissection on a goat head feels the same as on a human	4
Use of the surgical instruments feels the same as on a human	4
Use of the goat head model improved my ability to visualize the ear with the endoscope	4
Use of the goat head model improved my ability to use endoscopic ear surgical instruments	4
Global content validity	
Overall this was a valuable learning experience	5

have a deleterious effect on the understanding of human temporal bone surgical anatomy for junior or senior residents.

In common with other initial validation studies of simulation models, this study relied primarily on subjective learner-reported data. Further investigation could provide additional information on the utility of the caprine model in otologic surgical training. A current challenge in endoscopic ear surgery education is the lack of validated objective measures to track learner progress. While there are some impressive examples within the literature of assessment tools, they are either unvalidated or were developed for use in microscope-guided ear surgery.[5,11,12,18] Development of expert consensus on key steps or a tool such as an objective structured assessment tool would allow for a more objective assessment of the goat head model and offer a means of tracking learner progression through the course of a surgical skills curriculum.[19] A benefit of endoscopic surgery in a simulation or operating room is the ability to easily record video of the procedure for subsequent analysis. Advances in machine learning and automated video evaluation may soon mean that review of surgical skills sessions can be automated and far less onerous for the instructor.[20] The metrics used by an automated assessment system remain to be delineated. Potential parameters include duration of surgical steps, efficiency of hand and instrument movement (minimization of repetitive movements), and iatrogenic injury.[12]

This study did not directly compare the ovine and caprine models and, as such, it is difficult to draw conclusions about which is more suitable for educational purposes. As previously mentioned, we were unable to use the ovine model due to local health regulations. Based upon a review of published literature on the ovine model, both models seem to have quite similar morphology and anatomical differences relative to the human middle ear.[9,12] Chief among these is a prominent anterior canal which necessitates a large canalplasty. As well, there is a relatively large pars flaccida and absent scutum. In both models, the ossicular structure seems suitably similar to human middle ears with variable ligamentous support and mucosal bands relative to the human ear. The frequency of facial nerve dehiscence was not recorded but seems less frequent than in the ovine model.

This study focused on the index procedures of tympanoplasty and ossiculoplasty. These procedures require an array of skills and basic competencies that can be adapted to other procedures. For example, raising a tympanomeatal flap and drilling a canalplasty is a key step in many procedures requiring access to the middle ear. Manipulating the ossicles and dissection of soft tissue could be adapted to cholesteatoma surgery. Further studies could include additional procedures and the development of a cholesteatoma model.

CONCLUSION

The caprine model offers an effective, readily available, economically viable simulation for training in endoscopic ear surgery. We currently use it to give otolaryngology residents endoscopic ear surgery experience before operating on patients. Further study would allow quantification of the impact of this model on the trainee's learning curve.

Ethics Committee Approval: Ethical committee approval was received from the Research Ethics Board at the Hospital for Sick Children, Toronto (Approval No: 1000076174).

Informed Consent: Written informed consent was provided by trainee participants.

Peer-review: Externally peer-reviewed.

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