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Live Porcine Model for Surgical Training in Tracheostomy and Open-Airway Surgery

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Objectives/Hypothesis: To evaluate the validity of a live porcine model for surgical training in tracheostomy and open-airway surgery.

Study Design: Prospective observational study.

Methods: Eleven expert otolaryngologists–head and neck surgeons rated a live porcine model's realism/anatomical accuracy (face validity) and perceived effectiveness as a training tool (content validity) for tracheostomy and laryngotracheoplasty using anterior costal cartilage and thyroid ala cartilage grafts using a 53-item post-trial questionnaire with a five-point Likert scale.

Results: Experts rated the face validity of the live porcine model a median (interquartile range [IQR]) of 4/5 (4–5) and the content validity a median (IQR) of 5/5 (4–5) for each surgical procedure. Overall, 91% strongly agreed or agreed that the simulator would increase trainee competency for tracheostomy and laryngotracheoplasty using costal cartilage graft, and 82% strongly agreed or agreed that it would increase trainee competency for laryngotracheoplasty using thyroid ala cartilage graft.

Conclusions: The live porcine model has high face and content validity as a training tool for tracheostomy and laryngotracheoplasty using costal cartilage and thyroid ala cartilage grafts. This training model can help surgical trainees practice these complex, low-frequency procedures.

Key Words: Tracheostomy, laryngotracheoplasty, animal model, simulation, costal cartilage graft, airway reconstruction, porcine.

Level of Evidence: NA

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INTRODUCTION

Tracheostomy and open-airway surgery are complex, low-frequency procedures that require advanced training. Challenges of resident work-hour restrictions and low case volumes limit learning opportunities for surgical trainees in the operating room.[1–3] Surgical simulation is a growing area of research, as it can provide valuable opportunities for residents and fellows to learn and refine technical skills without risk to patient safety.

Various training modalities, including human cadavers, animal models, synthetic models, and virtual reality simulators, have been used to simulate microlaryngoscopy and microsurgery, tonsillectomy, needle biopsy of thyroid nodules, and cricothyroidotomy.[4,5] Synthetic three-dimensionally printed simulators are able to create highly accurate anatomical representations of human anatomy and have undergone early validation for airway procedures.[6–8] However, these simulators have not yet perfected the natural feel of living tissue and do not yet simulate bleeding. Our group published a surgical dissection manual teaching tracheostomy and open-airway surgery in a porcine model.[9] A recent systematic review of simulated laryngotracheal reconstruction animal models identified pig and lamb as being more suitable than rabbit for graft placement due to differences in laryngeal anatomy and cartilage texture.[10] However, animal models have not yet been validated as a simulation tool for tracheostomy and laryngotracheoplasty.[10] Moreover, many animal models are ex vivo cadaveric prosections that lack many of the critical, real-world constraints present in live, in vivo surgery that trainees struggle with. The objective of this study was to investigate face and content validity of a live porcine model for simulating tracheostomy and laryngotracheoplasty.

MATERIALS AND METHODS

Simulation Session

Ethics approval was obtained from the Hospital for Sick Children Research Ethics Board. Experienced pediatric otolaryngologists–

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head and neck surgeons who attended as faculty at the 5th Toronto International Pediatric Open-airway Surgery Workshop were recruited (n = 11). Experts performed a tracheostomy, laryngotracheoplasty using anterior costal cartilage graft and laryngotracheoplasty using anterior thyroid ala cartilage graft on a live porcine model and then completed a questionnaire about their experience (Fig. 1).

Animal Model

The live animal workshop was approved by the Animal Care Committee at the Hospital for Sick Children. Participants performed the simulated surgical procedures on Yorkshire piglets weighing 10 to 15 kg. Animals were sedated with an intramuscular injection of akmezine (0.2 mL/kg) and were placed under anesthesia using isoflurane (5%) delivered by facemask. Animals were intubated with a 6.0-mm or 6.5-mm internal diameter cuffed Sheridan endotracheal tube (ETT; Teleflex Medical, Research Triangle Park, NC), and anesthesia was maintained using isoflurane 3%. ETT cuff pressure was maintained at 20 cm H_2O using a Magnehelic manometer (Dwyer Instruments, Michigan City, IN). Heart rate, respiratory rate, oxygen saturation, and carbon dioxide levels were monitored throughout the surgical procedures by experienced animal care facility technicians.

Postsimulation Questionnaire

Each participant was given an anonymous questionnaire to rate the face validity and content validity of the live porcine model as a training tool. Questionnaire statements were specific to the three simulated surgical tasks (tracheostomy, laryngotracheoplasty using anterior costal cartilage graft, and laryngotracheoplasty using anterior thyroid ala cartilage graft). Participants were asked to rate their level of agreement with each statement on a five-point Likert scale (1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree). The questionnaire also included demographic and surgical experience questions, as well as a comment section for open-ended assessment/feedback. Participants were asked how much they would be willing to pay for using this model for training students as a proxy for how much they valued the model. Ordinal categorical Likert data for each question were analyzed, and the distribution of responses, median, and interquartile range were calculated.

RESULTS

Demographics and Surgical Experience

Eleven experienced otolaryngologists–head and neck surgeons from major airway centers across Canada and the United States completed the study. Demographic information and surgical experience of participants are summarized in Table I. The median (interquartile range [IQR]) number of years as an attending surgeon was 13 (7–15). Participants had performed a median (IQR) of 200 (150–300) tracheostomies, 40 (15–200) laryngotracheoplasties using costal cartilage graft, and six (5–20) laryngotracheoplasties using thyroid ala cartilage graft as primary surgeon.

Face and Content Validity

Regarding tracheostomy (Table II), all (100%) surgeons strongly agreed (64%) or agreed (36%) that the simulator would be a valuable training tool, 91% strongly agreed (64%) or agreed (27%) that use of the simulator would increase trainee competency, and 91% strongly agreed (55%) or agreed (36%) that they would use the simulator for teaching their trainees how to perform a tracheostomy. Overall, 87%

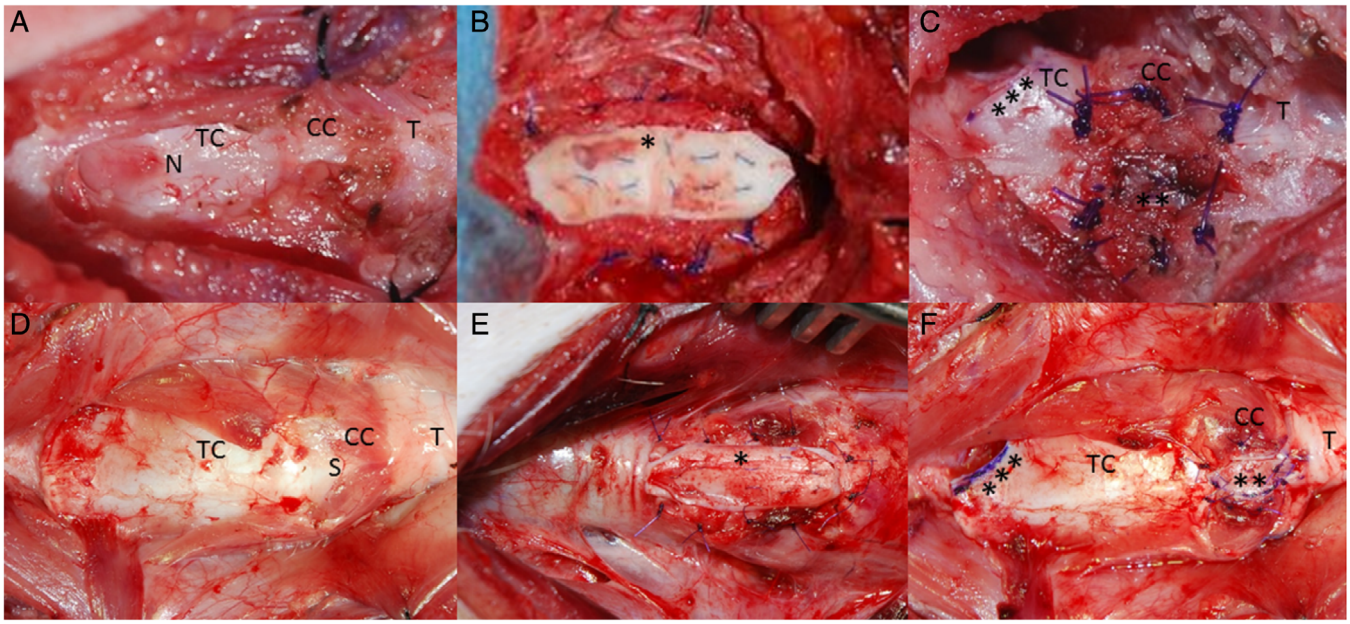

Fig. 1. (A–C) Human airway and (D–F) porcine airway: normal anatomy (A, D), anterior costal cartilage graft (B, E), anterior thyroid ala cartilage graft (C, F). Human airway (A) and porcine airway (D) have thyroid cartilage (TC), cricoid cartilage (CC), and trachea (T), but only human thyroid cartilage has a thyroid notch (N), and the porcine thyroid cartilage has a cartilaginous spike (S). Anterior costal cartilage graft (*) in human (B) and porcine (E) models. Anterior thyroid ala cartilage graft (**) in human (C) and porcine (F) models harvested from thyroid ala cartilage (***).

TABLE I.
Demographics and Surgical Experience of Participants.

No. of participants	11
Median age, yr (IQR)	45 (42–50)
Male, %	82%
Right handed, %	100%
Median years as an attending surgeon (IQR)	13 (7–15)
Country of practice	
Canada, %	36%
USA, %	64%
Median estimated no. of procedures performed as a primary surgeon (IQR)	
Tracheostomy	200 (150–300)
Laryngotracheoplasty using anterior costal cartilage graft	40 (15–200)
Laryngotracheoplasty using anterior thyroid ala cartilage graft	6 (5–20)

IQR = interquartile range.

strongly agreed (47%) or agreed (40%) that the simulator was realistic and anatomically accurate for teaching how to perform a tracheostomy.

For laryngotracheoplasty using anterior costal cartilage graft (Table III), all (100%) surgeons strongly agreed (64%) or agreed (36%) that the simulator would be a valuable training tool, 91% strongly agreed (64%) or agreed (27%) that use of the simulator would increase trainee competency, and 91% strongly agreed (55%) or agreed (36%) that they would use the simulator for teaching their trainees this procedure. Overall, 86% of respondents agreed (49%) or strongly agreed (37%) that the simulator was realistic and anatomically accurate for laryngotracheoplasty using anterior costal cartilage graft.

For laryngotracheoplasty using anterior thyroid ala cartilage graft (Table IV), 91% of surgeons strongly agreed (55%) or agreed (36%) that the simulator would be a valuable training tool, 82% strongly agreed (55%) or agreed (27%) that use of the simulator would increase trainee competency, and 81% strongly agreed (45%) or agreed (36%) that they would use the simulator for teaching their trainees this procedure. Overall, 80% of respondents agreed (46%) or strongly agreed (34%) that the simulator was realistic and anatomically accurate for laryngotracheoplasty using anterior thyroid ala cartilage graft.

Feedback regarding the three simulated procedures was generally positive (Tables II–IV). Experts rated face

TABLE II.
Summary of Questionnaire Results for Tracheostomy (N = 11).

	Likert Score						
Questionnaire Item	1, Strongly Disagree	2, Disagree	3, Neutral	4, Agree	5, Strongly Agree	Median	IQR
Realism/anatomical accuracy							
1. The surface anatomy is realistic on palpation for planning the skin incision.	0 (0%)	0 (0%)	4 (36%)	5 (45%)	2 (18%)	4.0	3.0–4.0
2. Incising the skin feels realistic.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
3. Incising, retracting, and/or removing the fat feels realistic.	0 (0%)	0 (0%)	3 (27%)	3 (27%)	5 (45%)	4.0	3.0–5.0
4. The blood vessels appear realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
5. The musculature appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	6 (55%)	4 (36%)	4.0	4.0–5.0
6. Dividing and retracting the sternohyoid and sternothyroid muscles feels realistic.	0 (0%)	0 (0%)	0 (0%)	7 (64%)	4 (36%)	4.0	4.0–5.0
7. The thyroid gland appears anatomically accurate.	1 (9%)	2 (18%)	3 (27%)	5 (45%)	0 (0%)	3.0	2.0–4.0
8. The trachea appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
9. Incising the trachea feels realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
10. Placing retention/stay sutures in the cut edges of the trachea feels realistic.	0 (0%)	0 (0%)	1 (9%)	2 (18%)	8 (73%)	5.0	4.0–5.0
11. Maturing the stoma by suturing the skin to the tracheal cartilage feels realistic.*	0 (0%)	0 (0%)	0 (0%)	5 (50%)	5 (50%)	4.5	4.0–5.0
12. Inserting the tracheostomy tube feels realistic.	0 (0%)	0 (0%)	1 (9%)	3 (27%)	7 (64%)	5.0	4.0–5.0
13. Suturing the flanges of the tracheostomy tube to the skin feels realistic.*	0 (0%)	0 (0%)	0 (0%)	3 (30%)	7 (70%)	5.0	4.0–5.0
Perceived effectiveness							
14. The simulator is a valuable training tool for tracheostomy.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
15. Use of this model will increase trainee competency when performing a tracheostomy.	0 (0%)	0 (0%)	1 (9%)	3 (27%)	7 (64%)	5.0	4.0–5.0
16. I would use this simulator for teaching my trainees.	1 (9%)	0 (0%)	0 (0%)	4 (36%)	6 (55%)	5.0	4.0–5.0

*For items 11 and 13, n = 10.
IQR = interquartile range.

TABLE III.
Summary of Questionnaire Results for Anterior Laryngotracheoplasty Using Anterior Costal Cartilage Graft (N = 11).

Questionnaire Item	Likert Score					Median	IQR
	1, Strongly Disagree	2, Disagree	3, Neutral	4, Agree	5, Strongly Agree		
Realism/anatomical accuracy							
1. The surface anatomy is realistic on palpation for planning the skin incision.	0 (0%)	0 (0%)	4 (36%)	5 (45%)	2 (18%)	4.0	3.0–4.0
2. Incising the skin feels realistic.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
3. Incising, retracting, and/or removing the fat feels realistic.	0 (0%)	0 (0%)	3 (27%)	3 (27%)	5 (45%)	4.0	3.0–5.0
4. The blood vessels appear realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
5. The musculature appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	6 (55%)	4 (36%)	4.0	4.0–5.0
6. Dividing and retracting the sternohyoid and sternothyroid muscles feels realistic.	0 (0%)	0 (0%)	0 (0%)	7 (64%)	4 (36%)	4.0	4.0–5.0
7. Suturing the sternohyoid and sternothyroid muscles to the skin laterally feels realistic.*	0 (0%)	0 (0%)	0 (0%)	7 (70%)	3 (30%)	4.0	4.0–5.0
8. The thyroid gland appears anatomically accurate.	1 (9%)	2 (18%)	3 (27%)	5 (45%)	0 (0%)	3.0	2.0–4.0
9. The trachea appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
10. Incising the trachea feels realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
11. The cricoid cartilage appears anatomically accurate.	0 (0%)	2 (18%)	4 (36%)	4 (36%)	1 (9%)	3.0	3.0–4.0
12. Incising the cricoid cartilage feels realistic.	0 (0%)	0 (0%)	2 (18%)	6 (55%)	3 (27%)	4.0	4.0–5.0
13. Carving the simulated costal cartilage graft feels realistic.	0 (0%)	0 (0%)	0 (0%)	6 (55%)	5 (45%)	4.0	4.0–5.0
14. Suturing through the costal cartilage graft and the cricoid/tracheal cartilage feels realistic.	0 (0%)	0 (0%)	0 (0%)	6 (55%)	5 (45%)	4.0	4.0–5.0
15. "Parachuting" the costal cartilage graft into the defect feels realistic.	0 (0%)	0 (0%)	0 (0%)	7 (64%)	4 (36%)	4.0	4.0–5.0
Perceived effectiveness							
16. The simulator is a valuable training tool for laryngotracheoplasty using anterior costal cartilage graft.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
17. Use of this model will increase trainee competency when performing laryngotracheoplasty using anterior costal cartilage graft.	0 (0%)	0 (0%)	1 (9%)	3 (27%)	7 (64%)	5.0	4.0–5.0
18. I would use this simulator for teaching my trainees.	1 (9%)	0 (0%)	0 (0%)	4 (36%)	6 (55%)	5.0	4.0–5.0

*For item 7, n = 10.
IQR = interquartile range.

validity an overall median (IQR) of 4 (4–5) for each procedure and content validity an overall median (IQR) of 5 (4–5). The lowest-scoring items (median 3) were related to the anatomical accuracy of the thyroid gland, cricoid cartilage, and thyroid cartilage.

Cost Estimate

Experts were willing to pay a median (IQR) of $500 CAD ($240–$1,409) for one live porcine model for teaching trainees. Reported values ranged from $150 to $5,000 per live porcine model.

DISCUSSION

Tracheostomy and open-airway surgical procedures are invasive high-risk procedures that require advanced training. With the added challenge of low-case volumes, mastering these skills in the operating room is becoming progressively difficult for trainees. Surgical simulation can help trainees in various surgical fields develop and practice these, and many other valuable airway procedures, in a low-risk environment. The present study evaluated the realism/anatomical accuracy (face validity) and perceived effectiveness (content validity) of a live porcine model for tracheostomy and open-airway surgical education.

Overall, experienced surgeons in this study believed that the porcine simulator had excellent face and content validity for surgical training in tracheostomy, laryngotracheoplasty using anterior costal cartilage graft, and laryngotracheoplasty using anterior thyroid ala cartilage graft. In the open feedback section, experts highlighted that the realism of tissue properties, bleeding, respiration, and movement contributed to these scores. Examples of comments included: "Works well. It mimics the human pediatric model. Likes: Realism, including bleeding, respiration, and movement. If trach placement, resection, slide, and costal cartilage grafting are going to be simulated, the pig is a good choice. The experience of operating on a live model for open and endoscopic airway procedures still has a unique value. Great model for any open-airway surgery technique." The

TABLE IV.
Summary of Questionnaire Results for Anterior Laryngotracheoplasty Using an Anterior Thyroid Ala Cartilage Graft (N = 11).

Questionnaire Item	Likert Score					Median	IQR
	1, Strongly Disagree	2, Disagree	3, Neutral	4, Agree	5, Strongly Agree		
Realism/anatomical accuracy							
1. The surface anatomy is realistic on palpation for planning the skin incision.	0 (0%)	0 (0%)	4 (36%)	5 (45%)	2 (18%)	4.0	3.0–4.0
2. Incising the skin feels realistic.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
3. Incising, retracting, and/or removing the fat feels realistic.	0 (0%)	0 (0%)	3 (27%)	3 (27%)	5 (45%)	4.0	3.0–5.0
4. The blood vessels appear realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
5. The musculature appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	6 (55%)	4 (36%)	4.0	4.0–5.0
6. Dividing and retracting the sternohyoid and sternothyroid muscles feels realistic.	0 (0%)	0 (0%)	0 (0%)	7 (64%)	4 (36%)	4.0	4.0–5.0
7. Suturing the sternohyoid and sternothyroid muscles to the skin laterally feels realistic.*	0 (0%)	0 (0%)	0 (0%)	7 (70%)	3 (30%)	4.0	4.0–5.0
8. The thyroid gland appears anatomically accurate.	1 (9%)	2 (18%)	3 (27%)	5 (45%)	0 (0%)	3.0	2.0–4.0
9. The trachea appears anatomically accurate.	0 (0%)	0 (0%)	1 (9%)	5 (45%)	5 (45%)	4.0	4.0–5.0
10. Incising the trachea feels realistic.	0 (0%)	0 (0%)	0 (0%)	4 (36%)	7 (64%)	5.0	4.0–5.0
11. The cricoid cartilage appears anatomically accurate.	0 (0%)	2 (18%)	4 (36%)	4 (36%)	1 (9%)	3.0	3.0–4.0
12. Incising the cricoid cartilage feels realistic.	0 (0%)	0 (0%)	2 (18%)	6 (55%)	3 (27%)	4.0	4.0–5.0
13. The thyroid cartilage appears anatomically accurate.	0 (0%)	3 (27%)	4 (36%)	4 (36%)	0 (0%)	3.0	2.0–4.0
14. Incising the thyroid cartilage feels realistic.	0 (0%)	0 (0%)	2 (18%)	5 (45%)	4 (36%)	4.0	4.0–5.0
15. Suturing through the thyroid ala graft and the cricoid/tracheal cartilage feels realistic.	0 (0%)	1 (9%)	1 (9%)	4 (36%)	5 (45%)	4.0	4.0–5.0
16. "Parachuting" the thyroid ala graft into the defect feels realistic.	0 (0%)	0 (0%)	1 (9%)	6 (55%)	4 (36%)	4.0	4.0–5.0
Perceived effectiveness							
17. The simulator is a valuable training tool for laryngotracheoplasty using anterior thyroid ala cartilage graft.	0 (0%)	0 (0%)	1 (9%)	4 (36%)	6 (55%)	5.0	4.0–5.0
18. Use of this model will increase trainee competency when performing laryngotracheoplasty using anterior thyroid ala cartilage graft.	0 (0%)	0 (0%)	2 (18%)	3 (27%)	6 (55%)	5.0	4.0–5.0
19. I would use this simulator for teaching my trainees.	1 (9%)	1 (9%)	0 (0%)	4 (36%)	5 (45%)	4.0	4.0–5.0

*For item 7, n = 10.
IQR = interquartile range.

high ratings are congruous with feedback we have received from our surgical dissection manual for tracheostomy and open-airway surgery in a live porcine model. Studies evaluating live porcine models for surgical training in other specialties (gastroenterology, urology) have reported similar face and content validity scores, and also concluded that realistic tactile feedback from live tissues, bleeding, and breathing movements contributed to high scores.[11–13] Similar scores have also been reported in studies evaluating cadaveric animal models for surgical training in rhinology[14] and laryngology.[15–17] Despite similar scores, the realism of cadaveric animal models was limited by the lack of bleeding[14] and difficulty making a skin incision in dissected larynx/trachea models with porcine skin stapled over the top.[16] It is important to note that questionnaire items relating to realism and anatomical accuracy in this study also provide evidence for content validity within the contemporary framework of simulation validation described by Messick.[18]

Lower-scoring questionnaire items were specifically related to the anatomical accuracy of the thyroid gland, cricoid cartilage, and thyroid cartilage. Porcine and human larynges have distinct anatomical differences (Fig. 1). The porcine thyroid gland does not wrap around the trachea to abut the recurrent laryngeal nerves, and it lies higher in the neck over the cricoid so that it needs to be removed to gain exposure to the cricoid and trachea.[9] The porcine thyroid and cricoid cartilages are more anterior related to the trachea as compared with humans, the porcine thyroid cartilage does not have a notch, and there is an inferior cartilaginous spike.[9] These anatomical differences can be confusing the first time they are encountered on a porcine model, and the surgeon must adapt the surgery accordingly. Interestingly, one expert said they would likely not use a porcine model if thyroid ala cartilage graft simulation was the only procedure to be performed.

Limitations of using a live porcine model for surgical training are the need for a specialized animal facility with experienced personnel, and the financial costs. Specialized facilities can help immensely with pig procurement, feeding, housing, inhalational, and intravenous therapy for anesthesia,

a surgical technical assistant, cleanup and disposal, and instrument cleaning and preparation. The animal facility used in this study charges approximately $2,150 CAD per pig for external users and $1,650 CAD per pig for employees of the hospital. Experts were willing to pay a median (IQR) of $500 CAD ($240–$1,409) for one live porcine model, suggesting that live animal models may be cost-prohibitive for some institutions. Departmental educational budgets may have influenced the reported values and will often impact what type of simulators are implemented.

A limitation of this study is that we did not investigate construct validity to determine if the model can distinguish between different levels of surgical experience and thus confirm that the model could be used to evaluate surgical competence. This is a future goal of investigation. In addition, although the comprehensive questionnaire was adapted from previous studies,[19,20] it was not formally validated for our study, and no definition of competence was given to participants for the second perceived effectiveness question for each procedure. Different responses to this question may result from varying definitions of competence among raters rather than the true utility of the porcine model.

CONCLUSION

The live porcine model has high face and content validity as a training tool for tracheostomy and laryngotracheoplasty using anterior costal cartilage and thyroid ala cartilage grafts. This training model can help surgical trainees practice these complex, low-frequency procedures. Implementation of live porcine models into the training curriculum has the potential to enhance education of tracheostomy and open-airway surgical procedures.

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