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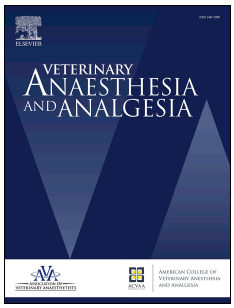

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SHORT COMMUNICATION

Running head (Authors) *M Clausse et al.*

Running head (short title) Simulator for cat orotracheal intubation

A low-cost portable simulator of a domestic cat larynx for teaching endotracheal intubation

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Abstract

Objective To design and construct an affordable simulator of the cat larynx for training intubation maneuvers and to share the designs for its fabrication.

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Study design Research and development study.

Animals One domestic cat.

Methods The cadaver of a cat, dead by natural causes, was frozen in sternal recumbency with the neck extended and the mouth wide open. A computed tomography (CT) image was acquired and used to construct a digital three-dimensional (3D) model of the pharynx and trachea. A digitally adapted model was 3D-printed and used to generate a silicone model of these structures, which was placed within a wooden container. The quality of the simulator was assessed by 46 veterinary anesthesiologists and veterinarians with experience in tracheal intubation maneuvers, and their opinions were obtained through an anonymous questionnaire.

Results Several preliminary prototypes were assessed regarding stability, texture and cost. Finally, a silicone model of a cat larynx (LaryngoCUBE) was produced and encased in a wooden container. Results from the questionnaire showed high scores regarding anatomy, tissue texture and intubation maneuver realism, compared with the real procedure.

Conclusions and clinical relevance Use of LaryngoCUBE as a training tool may improve the skills of students and reduce the use of animals for teaching endotracheal intubation. Blueprints and computational models are provided online so that the simulator can be fully reproduced.

Keywords cat manikin, endotracheal intubation, three-dimensional printing, training, upper airway management.

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Introduction

Appropriate management of the airway is essential for safe anesthesia in every species, yet junior graduates are not well trained in this area (Duncan et al. 2014). Endotracheal intubation of cats may be difficult and associated with complications because they have a small oropharynx and are susceptible to laryngeal spasm (Robertson et al. 2018).

As for other procedures and maneuvers, gradual training before performing the procedure on live animals is convenient, particularly when learning complex skills (Stringer et al. 2002). Although the training of hands-on skills in veterinary education has traditionally relied on the use of live animals, the use of simulated environments in human medicine are proven alternatives to promote proficiency (Hettinger & Haas 2003; Getto et al. 2016).

Nowadays, the processing and simulation of medical images represent innovative tools in an increasing number of situations ranging from simulation-based medical planning to risk assessment analysis. Among other technologies, three-dimensional (3D) printing is now a leading manufacturing technique for a wide range of applications in healthcare and medicine, including prosthetics, tissue replacements, anatomical models and patient-specific surgery planning.

This study aimed to develop a low cost, portable, easily reproducible model of a cat larynx constructed from a computed tomography (CT) scan, to simulate oral endotracheal intubation in cats. The motivation for developing the model arose from the current context of animal welfare, limited available resources of veterinary schools and overcrowded classes. The main goals of this study were 1) to provide veterinary educators and students with a useful tool for learning the technique of endotracheal intubation in cats; 2) to maximize the fidelity of the simulated anatomical structures; 3) to establish an effective methodology for constructing such

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tool; and 4) to minimize costs using materials and techniques that are available worldwide.

Materials and methods

Generation of the 3D mold

The cadaver of a Domestic Shorthair cat aged 6 years and weighing 3.15 kg, dead from acute kidney failure, was frozen in sternal recumbency with the neck extended and the mouth wide open. CT scan image (LightSpeed Ultra GE Medical Systems Device; General Electric Company, MA, USA) was processed in the ImageLab software (Version 2.164; HeMoLab Limitada, RJ, Brazil) (Hadlich et al. 2012). Through a threshold operation used to binarize the image using the air value in the Hounsfield scale (–650 for our CT model) (Fig 1.1), a digital surface (mesh) of the head and airway was created. Then it was manually clipped and smoothed using ParaView Version 5.3 (Kitware Inc., NY, USA) (Fig. 1.2).

Finally, manual corrections of minor anomalies resulting from the use of a cadaver were performed, including (a) enhancing the epiglottis and separating it from the tongue, (b) enhancing and separating the arytenoid cartilage, (c) elimination of the nasopharyngeal airway from the model; (d) enlarging the model by 20% (because the cat was smaller than average), (e) cutting and replacing the model boundaries with regular tubular extensions and (f) adding a wedge to the structure to facilitate the fixation of the mold to the container during the silicone filling (Fig 1.3). Organic modeling was performed with Sculptris (Pixologic Inc., CA, USA). Editing and modeling of auxiliary structures was made with AutoDesk 3DS Max (Autodesk Inc., CA, USA). The surface was visualized and autocorrected with Windows 3D Builder (Microsoft Corporation, WA, USA). Final lamination and preparation for 3D printing was achieved with CURA Version 4.0 (Ultimaker B.V., The Netherlands). To avoid support structures and to ensure

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the strength of the mold, it was designed as two flat based parts to be glued with cyanoacrylate adhesive and printed with a Prusa i3 Steel RepRap machine, in sagittal direction (Fig. 1.3 and Supplementary information), using polylactide (PLA) (Grilon3, Argentina) with 0.2 mm layer thickness, 1.2 mm wall thickness, 15% infill and 40 mm second^{-1} printing velocity with layer fan.

Construction of the physical model

Prototypes were made during the design process using different containers for the mold: i) a plastic cup, ii) a solid silicon prism container and iii) the final wood prism. To build this last model, a cylindrical cavity of 3 cm diameter and 10 cm length was drilled at 45 degrees into one face of a 10 × 10 × 13 cm wood prism. The lumen matrix was inserted in the cavity and the space between the matrix and the wood was filled with pink colored room-temperature-vulcanizing (RTV) silicone: a two-component silicone rubber mixed with a catalyst in a 5% ratio (Code RTV 6211; Silicon Argentina S.R.L., BA, Argentina). The lumen matrix was removed from the mold after 24 hours (Fig. 1.3; Supplementary Information: Manufacturing details).

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Testing and assessment

The final prototype (LaryngoCUBE; Fig. 1.4) was evaluated by 46 veterinarians and veterinary anesthesiologists experienced with the intubation procedure at the IIIth Congress of the Argentine Association of Veterinary Anesthesiology and Analgesia (AAAVRA), 2019. During the two-day meeting, the simulator was available at a stand. Throughout the breaks, veterinarians were invited to evaluate it and immediately after the simulator was tested, professionals answered an anonymous questionnaire and placed it in an urn.

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Statements were related to 1) the anatomical similarity of the larynx, 2) similarity of the artificial materials with cat laryngeal tissues, 3) similarity of the simulated intubation with the intubation of a real cat, and 4) relevance of the simulator regarding learning the endotracheal intubation procedure. Each statement was evaluated using a visual analogue scales (VAS), ranging from a score of 1 (disagree) on the left to score 10 (totally agree) on the right. An open question was available for additional comments. The results of the questionnaire were processed using descriptive statistical analysis of the responses, including average, standard deviation, median, mode and interquartile range.

Results

Mold and casting

The first raw 3D model of the cat airway generated from the CT image of the cadaver needed various manual adjustments to emulate the position of the epiglottis and arytenoid cartilages in a live cat.

The material selected for 3D printing was silicone rubber PLA, which provided the strength required for unmolding without damage. The silicone rubber is an elastic solid with high tensile strength, similar to the soft tissue of the relevant anatomical region. Although silicones are usually degassed prior to pouring to minimize bubble entrapment, this processing was not necessary for this model. Instead, care was taken to tilt the prism a few times and free air bubbles that could have been trapped in the cavities of the mold.

Prototypes

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A plastic cup was used in the first prototype. The simulator was small (200 mL), light and inexpensive (current US dollars (US$) 8 for silicone and US$ 15 for the 3D printed mold), but required being held manually. Hence, it would have failed as intubation training simulator because the correct maneuver requires the use of both hands, one for holding the laryngoscope and the other for holding the tube.

The second prototype was cast in a 3D-printed 7 × 7 × 10 cm silicone prism, which can be placed in a stable position on a flat surface, leaving both hands free for the trainee to practice intubation. The problem with this prototype was that the printing process was long (12 hours) and the material more expensive: (20 US$ for 500 mL silicone and 60 US$ for 3D printing).

The third prototype was cast in a 3D-printed hollow cat head, modeled from the original CT image. This approach gave a realistic appearance but the head was too fragile and the production cost was high (60 US$).

The final version of the simulator was built in a cube made of low density wood (*Pinus lambertiana*), which is cheap (4 US$), available everywhere and eco-friendly. The final weight of the simulator is 650 g, enough to ensure a stable position required for practicing intubation. The final model required 50 mL of silicone (2 US$), the 3D-printed mold (15 US$) and 3 hours of printing. The mold is printed once and re-used for fabrication of multiple simulators.

Evaluation

The 46 veterinarians, using a 0–10 scale, scored anatomical fidelity, material fidelity and maneuver similarity at 8.3 ± 1.2, 7.7 ± 1.9 and 7.2 ± 2.3, respectively, mean ± standard deviation. The mode (interquartile range) for each parameter was 8 (8, 9), 8 (7, 9) and 8 (5.5, 9), respectively. The lowest responses were followed by additional comments pointing out that the

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realism could be improved by emulating laryngospasms and movements of the epiglottis when the tongue is displaced, and including a model of the cat head. There was a general consensus among the participants on the advantages of the tool for developing skills in endotracheal intubation, especially for undergraduate practices. The corresponding mode (interquartile range) was 10 (10, 10).

Discussion

The development of a simulator of the cat larynx (LaryngoCUBE) for training in oral endotracheal intubation was described, including the prototyping stages and decision paths towards the final device.

Testing and assessment of the present model by veterinarians experienced in tracheal intubation of the cat showed positive scores relating to anatomy, material and fidelity. These results support the quality of the design, providing the necessary confidence for reliable application in training and practice. A limitation of the survey is that the reference for comparison was indirect, namely, the participants used their memory of the procedure in live cats. Authenticity is a necessary but not a sufficient element for validation. The degree of fidelity may be independent of educational effectiveness, in that a simulator could be viewed as having high or low fidelity depending on which features are emphasized or ignored, and, furthermore, that fidelity requirements vary depending on the training task (Hamstra et al. 2014). In the present study, in spite of the little resemblance that the wood case bears with a cat, the anatomic similarity was highly rated, a result of focusing on the inner tissue structure. A plain outside case may be an advantage by minimizing distractions. The accuracy in the anatomic structure of the larynx, and the similarity of silicone to soft tissues could be sufficient resemblance to intubation

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in live animals. Future assessments will focus on determining the teaching efficiency of the simulator for acquisition of manual skills by students.

Further improvements to overcome the limitations of the present design, especially the lack of movement of the epiglottis and extension of the tongue, will include searching for new materials with properties that more closely imitate the tissue textures and flexibility and facilitate reflexes and movements, and the shape of the external case. Furthermore, the methodology presented here could be extended to production of simulators for endotracheal intubation of other animal species, such as rabbit, dog, pig or sheep.

The use of simulation is continuously growing and evolving in veterinary medicine, to keep pace with the increased demand for hands-on training without the use of live animals (Scalese & Issenberg 2005; White et al. 2017). Following a literature search, no other publication was found describing the development of an intubation simulator using 3D printing technology from a medical image. Currently, a few expensive commercial simulators are offered for intubation training in companion animals, for example, simple intubation manikins (Paw 2 Claws Animal Manikins, CA, USA; Vet Effects Inc., CA, USA; Forma Fundo, The Netherlands; 700–1000 US$) to more complex simulators (TraumaFX Solutions Inc., GA, USA and SynDaver Labs, FL, USA; > 5000 US$). As a consequence of the high cost of acquisition and maintenance, use of simulators is limited in veterinary schools. LaryncoCUBE was developed in the spirit of open and inclusive knowledge production and the promotion of open educational resources. The blueprints for construction are freely available under a NonCommercial CC license and can be downloaded from http://www.vet.unicen.edu.ar/HEPA/investigacion/LaryngoCUBE or www.plademа.net/LaryngoCUBE. In this way, anyone can assemble and use the simulator for teaching endotracheal intubation in cats at a current cost of 15 US$.

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Conclusion

Endotracheal intubation is a crucial life-saving procedure, where failed attempts can lead to further complications or even death. Like all technical skills, it requires sufficient practice to perform adequately. LaryngoCUBE is a low-cost educational tool that can be fabricated with common household and inexpensive materials. Open-source access to LaryngoCUBE will improve accessibility to medical training in the hopes of optimizing patient care.

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Authors' contributions

MC, PN, FL, MJDS and AC: conception. PN and FL: animal cadaver tomography. AG and CAB: image processing and 3D model construction for 3D printing. AG: 3D printing of molds. MC: prototypes and final simulator fabrication. PN: organization of product evaluation. MC and CAB: data analysis. MC, CAB and AC: preparation of manuscript. All authors contributed to the iterative process of designing, testing and refining the final version of the simulator, and contributed to revision of the manuscript.

Conflict of interest statement

The authors declare no conflict of interest.

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References

Duncan JC, Ross M, Rhind S et al. (2014) Comparison of anaesthesia 'Day 1 skills' expectations between veterinary anaesthetists and general practitioners. Vet Rec 176, 230.

Getto LP, Marco D, Papas MA et al. (2016) The effect of noise distraction on emergency medicine resident performance during intubation of a patient simulator. J Emerg Med 50, e115–e119.

Hadlich MS, Oliveira GMM, Feijóo RA et al. (2012) Software livre e de código aberto para avaliação de imagens de angiotomografia de coronárias [Free and open source software for evaluation of coronary angiotomography images]. Arq Bras Cardiol 99, 944–951. [In English, Portugese]

Hamstra SJ, Brydges R, Hatala R et al. (2014) Reconsidering fidelity in simulation-based training. Acad Med 89, 387–392.

Hettinger LJ, Haas MW (2003) Virtual and Adaptive Environments: Applications, Implications, and Human Performance Issues (1st edn). CRC Press, UK.

Robertson SA, Gogolski SM, Pascoe P et al. (2018) AAFP feline anesthesia guidelines. J Feline Med Surg 20, 602–634.

Scalese RJ, Issenberg SB (2005) Effective use of simulations for the teaching and acquisition of veterinary professional and clinical skills. J Vet Med Educ 32, 461–467.

Stringer KR, Bajenov S, Yentis SM (2002) Training in airway management. Anaesthesia 57, 967–983.

White DM, Redondo JI, Mair AR, Martinez-Taboada F (2017) The effect of user experience and inflation technique on endotracheal tube cuff pressure using a feline airway simulator. Vet Anaesth Analg 44, 1076–1084.

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Supporting Information

Additional supporting information can be found at ……[to be completed by Production team]

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Figure legend

Figure 1 Steps in developing the cat intubation simulator. 1.1, the computed tomography (CT) image was binarized through a threshold operation using the air value in the Hounsfield scale: (a) sagittal and (b) horizontal cuts of the CT image are shown before and after the processing; 1.2, digital model of the skin and oropharynx-trachea airway; 1.3, 3-dimensional (3D) printed mold of the digital model and casting in the wood prism; 1.4, external view of the simulator (LaryngoCUBE): (a, b) views of the oropharynx and epiglottis, (c) view of the endotracheal tube inserted in the trachea (laryngoscope blade is placed on the dorsal surface of the epiglottis to facilitate photography but is not recommended for routine intubation in live animals).

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1.1
CT image segmentation
(a)
(b)
1.2
Raw mesh of skin and laryngotracheal airtube
1.3
3D printed mold & silicone casting
1.4
LaryngoCUBE
Final prototype
Internal views
(a)
(b)
(c)