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Design and Validation of a Three-Dimensional Printed Flexible Canine Otoscopy Teaching Model

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Introduction: A teaching model was sought to improve canine otoscopy skill and reduce use of teaching dogs.
Methods: An otoscopy teaching model was printed in a flexible medium on a desktop three-dimensional printer from a magnetic resonance image of a canine external ear canal. The model was mounted in a polyvinyl dog mannequin. Validation of the teaching model was sought from student, faculty, and dog perspective. Student perception of prelaboratory training was assessed using a survey regarding their experience. Otoscopy skill was assessed by faculty grading the ear anatomy visualized as well as the time required to prepare for and perform otoscopy and the time to the dog's first sign of aversion. The time data were used to assess whether there was a reduction in use of teaching dogs. Data from students exposed to the otoscopy model as part of their prelaboratory training (n = 20) were compared with those that were not exposed to the model (n = 19).
Results: The students found prelaboratory training with the model significantly more helpful than prelaboratory training without the model in all aspects of otoscopy ($P < 0.05$). Use of the model did not alter otoscopy skill (structures seen or time taken) or decrease dog use.
Conclusions: The students found the model helpful, but the best that can be said is the model did not negatively impact their otoscopy skill acquisition. Although the outcome of the study did not indicate a reduction in teaching dog use, the model has replaced live dog otoscopy in the institute's teaching program for initial canine otoscopy exposure.
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Key Words: ear, otoscopy, model, 3D printer, flexible, canine, veterinary, validation, design, competency, skills, MRI.

Otoscopy is considered a core component of a complete physical examination of the dog, and acquiring the skill to perform canine otoscopy is a common goal of our students during their canine physical examination laboratory training. The teaching dogs that serve in the laboratory find this examination somewhat aversive, particularly when done repeatedly or performed with little skill. Even in the hands of a skilled clinician, otoscopy occasionally causes discomfort to the dog, and it is particularly challenging in this species because of long vertical and horizontal portions of the ear canal. Performing otoscopy requires knowledge of anatomy as well as the development of hand skills to use the instrumentation to perform the skill of otoscopy quickly and to avoid causing discomfort to the dog.

The purpose of the study is to create and validate a three-dimensional (3D) printed ear model in a flexible medium for teaching otoscopy. Our hypotheses were that prelaboratory training with this teaching model would reduce the time to prepare for and complete the otoscopic examination on a live dog and would increase the time to signs of aversion in a live dog. We further hypothesized that students receiving prelaboratory training with the model would demonstrate improved otoscopy performance as assessed by faculty and would report greater satisfaction with their prelaboratory training. Decreasing dog use is important with regard to the 3Rs (replacement, reduction, and refinement) principle of Russell and Burch.[1] Improving clinical competency in day 1 skills is an important goal within veterinary curricula.[2] Desktop 3D printing allows for rapid prototyping and generation of inexpensive teaching models. The recent release of flexible filament with which to print allows for creation of flexible teaching models that behave similarly to biological specimens, such as the mostly cartilaginous ear canal. A 3D printer uses a digital file as input to create a print. If the original digital file is created by a magnetic resonance image (MRI) of a real anatomic specimen (a canine ear), the subsequent print should be a highly detailed and anatomically correct specimen.

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MATERIALS AND METHODS

This study received approval from the institutional review board and institutional animal care and use committee at Ross University School of Veterinary Medicine. Consent forms and all results were held in strictest confidence.

Model Development and Generation

An MRI of a normal canine head was converted from Digital Imaging and Communications in Medicine slices to a steriolithograph (STL) file with 3D Slicer, a multiplatform free, and open-source software tool for visualization and medical image computing. The STL file was then added to Autodesk Meshmixer, a free download at meshmixer.com (http://meshmixer.com), for working on the points and cleanup of the structure to isolate the needed structures: the entire external ear canal from the level of the tragus to the end of the vertical ear canal, excluding the tympanic membrane. Using Autodesk 123D Design, the isolated ear canal was inserted into a simple cylinder shape to create a printable file. The file was imported to MakerBot Desktop to create appropriate support structure with 10% infill, two shells, and 0.2-mm layer height.

A desktop printer, Makerbot Replicator 2X (New York, NY), was loaded with NinjaFlex 3D semitransparent 1.75-mm thermoplastic elastomer printing filament (Fenner Drives, Manheim, Pa). The printer settings were as follows: printer bed unheated and coated with masking tape, extruder heated to 230°C, extruding speed of 50 mm/s while printing and 150 mm/s while traveling.

The final dimensions of the 3D printed model are a 5 × 8-cm cylinder with an ear canal diameter of 1 to 0.5 cm. The print time using the previous setup is approximately 2 hours.

Postproduction modification was required to opacify the ear canal. This was completed with white acrylic paint applied to the interior surface of the ear canal. Otherwise, the lack of shadow when illuminated made identification of the approach to the vertical ear canal challenging.

An emerald green plastic bead was placed at the level of the tympanic membrane. The 3D printed ear canal model was then inserted into a commercially available black polyvinyl dog mannequin (18 in high, 6 in wide, and 27 in long) by East Side Collection. This was done by opening the seam in the mannequin head below the right pinna. A volume of stuffing was removed to allow for insertion of the ear model maintaining orientation of the vertical ear canal in cranial/medial directionality. The vinyl was adhered to the exposed base of the 3D printed ear canal model with a hot glue gun, and the seams were partially closed with a needle and thread leaving the ear canal open. The 3D print of the ear canal is presented in Figure 1.

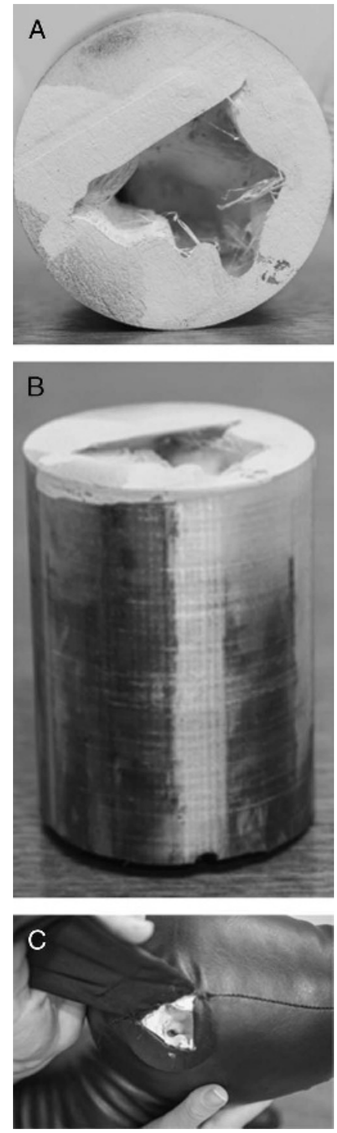

FIGURE 1. Images of 3D ear model. A, View of the 3D print from insertion point of the otoscope. White paint was applied to ear canal in postproduction. B, View of the 3D print from the side. C, The view of the 3D printed ear in the dog model. Note the dark central area that marks the directionality of the vertical ear canal.

Validation of the Otoscopy Model

Thirty-nine students scheduled for a live dog laboratory with otoscopy, which included prelaboratory reading assignments on otoscopy (text and diagrammatic representation of the otoscope and anatomy of the canine ear canal), were divided into a control population (n = 19) and an educational intervention population (n = 20). This division was based on random convenience: using their previously assigned laboratory schedules across three sessions where the first session was all controls, the second was all educational intervention, and the third was half controls and half educational intervention. Most students reported that they had not performed otoscopy before this laboratory session (n = 30), and the remaining students (n = 9) reported that they had performed otoscopy less than four times in the past. The students with experience were equally distributed by random chance across the two study groups (only known in hindsight) with four in the control group and five in the educational intervention group.

As much as possible, control population students did not see and were not aware of the existence of the educational model. The educational intervention population performed otoscopy on the educational model with individual guidance by a trained faculty member. This guidance involved assembly of the otoscope and complete otoscopy until visualization of the green bead in the ear canal at the level of the tympanic membrane was achieved. Students were not told that they were looking for a green bead. This session immediately preceded their live dog laboratory.

For each live dog laboratory, a complete physical examination was performed, and students worked in groups of two (with the exception of one group of three) on a single dog, taking turns as examiner and handler of the dog. There were five or six dogs in each laboratory session. There were nine different dogs used in the study across the three data collection sessions. Each dog was examined by two to three students per session where each student was permitted to examine one ear (unilateral) and the subsequent student examined the contralateral ear. There was a rest period of 1 to 2 weeks between sessions during which the time the dog did not have its ears examined. Where each unit is defined as unilateral ear examination, the average number of times a dog was used for otoscopy was 4.3 times (maximum, 7; minimum, 2; standard deviation, 2). Students were asked to wait to perform otoscopy on the dog until a specified faculty member (the same one for all students across all of the laboratory sessions) arrived at their station to coach them. A video camera with a wide-angle view elevated to dog eye level by a tripod was used to capture each dog's behavior and time line. For otoscopy, a 3.5 V Pneumatic Consulting Otoscope (Welch Allyn; Skaneateles Falls, NY) was used. This otoscope has two viewing lenses, which allowed the faculty member to verify the level of visualization within the ear canal. Students were individually coached through otoscope assembly and otoscopy. During and immediately after each student's performance of otoscopy, the faculty member used a grading rubric to assess otoscopy performance. This rubric assessed positioning of the student's hands and body in relationship to the dog and otoscope, method of pinna distraction, and level of visualization of the vertical and horizontal canals and tympanic membrane.

On completion of otoscopy at each station, each student completed a seven-point Likert scale survey assessing the helpfulness of their prelaboratory training in the same following five aspects assessed by the faculty member: positioning of their hands and body in relationship to the dog and otoscope, method of pinna distraction, and level of visualization of the vertical and horizontal canals and tympanic membrane, as well as the helpfulness of prelaboratory training in their overall knowledge of and confidence in performing otoscopy. They were also asked to indicate whether they had ever performed otoscopy before and, if yes, to indicate approximately how many times they had done so.

Video was used to measure time to prepare for otoscopy, time to perform otoscopy, and time to the dog's first show of aversion to otoscopy. The time each student took to prepare for otoscopy was defined as the time from first picking up the otoscope (includes assembly of the otoscope) to the time they first touch the dog's pinna. The time it took to perform otoscopy was defined as the time from insertion of the otoscope into the ear canal to the time it was removed. The time the dog first showed that aversion to otoscopy was defined as the time from the student first touching the pinna to the dog first showing either movement of their head or body away from the otoscope or from the handler.

Statistical Analyses

Survey and assessment data were evaluated both visually, for normality of distribution, with histograms and with descriptive statistics (mean, range, and standard deviation). A χ^2 test was used to evaluate whether intervention was related to any of the following variables: the seven survey questions (each with the following five categories: strongly agree, agree, neutral, disagree, strongly disagree) and five faculty assessments of otoscopy performance (with the following four categories: excellent, good, marginal, fail for the first two aspects of performance and two categories, yes or no, for the latter three aspects of performance). The nonparametric Kolmogrov-Smirnov test was used to compare the educational intervention and control groups for the following periods: time to preparation, time to perform otoscopy, and time to the dog's first sign of aversion. Results were presented as median, 25th percentile and 75th percentile. The statistical software Stata Version 13 was used for the analysis.

RESULTS

All survey and grading rubric data were found to be normally distributed. With regard to student perception of prelaboratory training, the educational intervention group found their prelaboratory training more helpful in all aspects of their learning, knowledge and confidence ($P \leq 0.05$). The survey data along with P values (from χ^2 tests) are presented in Table 1.

There were no significant differences in assessment of student performance of otoscopy between the control group and educational intervention group. The assessment data along with P values (from χ^2 tests) are presented in Table 2.

There were no significant differences between the study groups with regard to the time to prepare for (P = 0.81) or

TABLE 1. Student Survey Statements and their Level of Agreement Regarding Helpfulness of Prelaboratory Training

	Educational Intervention Group (n = 19)					Control Group (n = 20)					
The Prelaboratory Training Was Helpful:	SA	A	N	D	SD	SA	A	N	D	SD	P
1. In learning the correct positioning for examination (hand and body placement and instrumentation)	9	9	1	0	0	1	13	4	2	0	0.01
2. In learning to distract the ear	9	8	1	1	0	2	7	8	3	0	0.01
3. In learning to visualize the vertical ear canal	11	7	1	0	0	2	11	3	4	0	0.01
4. In learning to visualize the horizontal ear canal	9	9	1	0	0	1	5	5	9	0	0.00
5. In learning to visualize the tympanic membrane*	9	9	0	0	0	1	3	5	10	1	0.00
6. To increase knowledge of correct otoscopic examination technique	11	7	1	0	0	4	10	3	3	0	0.05
7. To increase confidence in performing otoscopy	10	5	2	2	0	1	7	9	2	1	0.01

The educational intervention group was exposed with the ear model, whereas the control group had traditional paper documents to describe the skill. Each P value is generated by a χ^2 test.
SA = strongly agree, A = agree, N = neutral, D = disagree, SD = strongly disagree.
*n = 18 for educational intervention group on this question as one student did not record a response to this question.

TABLE 2. Evaluation of Student Otoscopy Performance

	Educational Intervention Group (n = 19)				Control Group (n = 20)				
Evaluation of Skill Performance:	**3**	**2**	**1**	**0**	**3**	**2**	**1**	**0**	***P***
1. Shows the correct positioning for examination (hand and body placement and instrumentation)	0	19	0	0	0	18	0	2	0.16
2. Shows distraction of the ear	1	17	1	0	1	17	0	2	0.40
3. Visualizes the vertical ear canal	19	0	0	0	18	0	0	2	0.16
4. Visualizes the horizontal ear canal	5	0	0	14	4	0	0	16	0.64
5. Visualizes the tympanic membrane	0	0	0	19	0	0	0	20	1.00

A grading rubric for five aspects of otoscopy was used to assess student otoscopy. The first two aspects have a gradation of four levels from excellent to fail, and the latter three skills are yes/no marked as either a numeric 3 (yes) or 0 (no). Each *P* value is generated by a χ^2 test. 3 = excellent or yes, 2 = good, 1 = marginal, and 0 = fail or no where q3, 4, and 5 are yes/no.

perform otoscopy ($P = 0.71$) or in the time it took for the dog to first show signs of aversion ($P = 0.56$) (Table 3). Regarding aversion to otoscopy, dogs that immediately showed signs of aversion (occurred for 7 control students and 4 educational intervention students) were recorded as showing aversion within 2 seconds and dogs that did not show aversion at anytime (occurred for 7 control students and 9 educational intervention students) were recorded as showing aversion at 18 seconds (because this was the longest time taken to perform otoscopy). Because of strong aversion exhibited by dogs, three students (all control students) were unable to attempt to perform otoscopy. Because of missing or poor video, time data were missing or partial for three control students and one educational intervention student.

DISCUSSION

The process of 3D printing involves an initial phase of model design followed by model printing. One problem we faced in model design was figuring out how to create a perimeter for the build. This was solved by use of the primitive object (the cylinder) into which the selected portion of the STL could be inserted. A challenge of model printing was that the use of flexible medium made by a different manufacturer than the printer led to an increased need for trial and error regarding finding optimal printer settings (such as print speed, extruder temperature, platform temperature, and characteristics). The online community was very useful in providing hints for how to print in the flexible medium. Using rapid prototyping, as made possible by desktop 3D printing, we were able to move from an expensive proof-of-concept model through three generations of the print on the desktop printer, arriving at a highly functional model in a matter of four days.

As to the validation of the model, it is clear that students find it helpful, particularly in the most challenging level of the skill, visualizing the tympanic membrane, which was represented by a green bead in the model ($P = 0.00$). Regarding visualizing the tympanic membrane, 11 (55%) of the 20 control group students either disagreed or strongly disagreed that their prelaboratory training was helpful in learning this skill. Contrasting this, in the educational intervention group, 100% of the students agreed or strongly agreed (18/18) regarding the helpfulness of their prelaboratory training (which included the model) in learning to visualize the tympanic membrane. An important limitation to consider is that the students in the intervention group received additional training (over and above the text and diagram reading assignment that both groups completed) and that the additional time, particularly involving faculty contact, could explain the perceived helpfulness of the model to prelaboratory training. We would like to think that the model is an improvement over other teaching methods such as video supplement because it more closely approximates increased practice on the live dog. Increased practice on the live dog is considered undesirable because it goes against the 3Rs (replacement, reduction, and refinement) principle whereby dog use is decreased.[1] However, it is possible that any intervention could have led to the same improvement in student perception of prelaboratory training.

TABLE 3. Time Intervals Associated With Otoscopy

	Time in Seconds (Median, 25th–75th Percentile)		
Period	**Educational Intervention**	**Control**	***P***
Time to prepare for otoscopy	120, 115–160	135, 100–180	0.81
Time perform otoscopy	8, 5–10	9, 7–16	0.71
Time to dog's first sign of aversion	11.5, 3–2	5, 0.1–12	0.56

Using video analysis, the time required to get ready to perform otoscopy, the duration of time the otoscope was in the ear canal and the dog's tolerance of otoscopic examination represented as time to first sign of aversion were obtained.

The model was not proven to improve otoscopy skill when used in the manner of this study. Low study numbers likely limit our ability to show a difference. Furthermore, a single exposure to the model with guidance on its use of more than 10 minutes and a lack of time for self-reflection or ability to revisit and practice again also limit the impact of the model.[3] The lack of apparent negative impact should be considered an important observation because a poorly designed model has the potential to teach poor technique such as use of too much force, which might have been captured by dogs quickly showing aversion to otoscopy.[4]

The proof-of-concept STL file can be found on Thingiverse.com (Supplemental Digital Content 1, http://links.lww.com/SIH/A329) where it can be downloaded for free. The model continues to undergo modifications. Distracting the pinna allows for better otoscopy; therefore, an initial goal is to print a model that mimics the attribute of the normal ear canal of increasing the angle between the vertical and horizontal ear canal with distraction of the pinna. A postproduction modification that has been made to the study model is to paint the exterior of the ear canal (vs. the interior) in a flesh tone. Painting the interior led to some paint flaking that impaired visualization, and the white paint is presumed to have decreased the realism. Painting the exterior of the canal required cutting away some of the cylinder in which the ear canal is printed, and the result can be seen in

FIGURE 2. Next generation model. Postproduction modifications made to the model after the study improved realism and functionality by painting the exterior for the ear canal a flesh tone. This required cutting away a portion of the cylinder.

Figure 2. Alternatively, the print could be done in a natural color flexible filament (it is now available in blush color). Another idea is to print the cylinder and fill in dissolvable filament such that the final model is ear canal only.

There is tremendous potential to modify the model to show normal and pathologic presentations of the ear canal and tympanic membrane. Creation of a model to be used for diagnostic (myringotomy), therapeutic (foreign body removal, ear canal cleaning), and testing (a word or symbol at the tympanic membrane) purposes is another prospective use.

It was not possible to show a decrease in dog use in this study as reflected by either the time taken to perform otoscopy or the time it took for the dog to first show signs of aversion. Showing a difference in the time it takes for a dog to first show signs of aversion is particularly challenging given high degree of variability in the dog's tolerance both as individuals and over time. There are a great many variables that might impact this level of tolerance for which it is hard to control. Dogs are scheduled for particular laboratory sessions by kennel management based on university animal use policies taking into consideration individual animal performance in the past during particular laboratory sessions and current issues. As such, the highly trained teaching dogs showed great ability to tolerate otoscopy during the study with no signs of aversion in 41% (16/39) of otoscopic examinations. This is a credit to the training program that works continuously with the dogs to ensure their suitability as teaching dogs. This level of compliance in the dogs takes daily work with desensitization, so from both the dog's perspective and the resources required to carry such training out, use of a model is preferable to use of the teaching dogs. A further effect of working with the teaching dogs occurs when students are working with a dog that is not tolerant of otoscopy during that individual session (as did occur in this study where 3 students working with 2 different dogs were unable to attempt otoscopy). This means they lose an important learning opportunity and may lose confidence such that in future otoscopy sessions, they are tentative and perhaps less successful. Based on preliminary work with this model, students currently no longer perform otoscopy on the dogs but rather begin to develop their skill on the model in the introductory canine physical examination laboratory. Many other models may be suitable to printing, particularly in flexible medium. A digital rectal examination model including modifications with variable prostate findings is considered a priority.

CONCLUSIONS

Three-dimensional printing in a flexible medium from an MRI rapidly produced a canine otoscopy teaching model. The model used in prelaboratory training was well accepted by students, particularly in how it allowed for visualization of the tympanic membrane. Although we did not demonstrate improved otoscopy skills in students trained with this model, it can be said that the model did not teach poor technique in that students who used the model did not exhibit worse skills in otoscopy and the dogs were equally tolerant of students who had prelaboratory training that included the model compared with students who did not have access to the model. Further modification to the model as well as alternative study design using more time with the ear model in the prelaboratory training and larger student subject numbers are suggested as means of seeking a validated otoscopy model that both improves otoscopy skill and decreases dog use.

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