BRIEF REPORT

A low-cost otoscopy simulator increased confidence in mechanical otoscopy skills and tympanic membrane pathology identification among preclinical medical students during the COVID-19 pandemic [version 1; peer review: awaiting peer review]

Shiv H Patel1, Shady I Soliman2, Preetham Suresh1-3, Charles Goldberg2,4, Darcy Wooten2,4

1Simulation Training Center, UC San Diego School of Medicine, La Jolla, CA, 92093, USA
2School of Medicine, UC San Diego, La Jolla, CA, 92093, USA
3Department of Anesthesiology, UC San Diego, La Jolla, CA, 92093, USA
4Department of Medicine, UC San Diego, La Jolla, 92093, USA

Abstract

Background: Diagnostic evaluation of otologic diseases often requires otoscopy to visualize the tympanic membrane. The fundamentals of otoscopy include both learning the mechanics of using an otoscope and accurately identifying ear pathologies. During the COVID-19 pandemic, there was limited peer-to-peer physical exam practice for preclinical medical students. We developed a low-cost 3D-printed otoscopy simulator to teach the otoscopic exam to small groups of medical students.

Methods: A modified open-source 3-dimensional (3D) head was printed, and a silicone ear was attached. A user interface was created to display one normal tympanic membrane and four pathologies. Preclinical medical students attended a didactic lecture on common otologic pathologies and on how to perform otoscopy. Students then practiced otoscopy and pathology identification on the simulator in small groups. After the session, students were provided an optional survey to evaluate their confidence in otoscopy skills and pathology identification.

Results: A total of 47 out of 134 (35%) medical students completed the survey, of whom 60% reported that training with the 3D printed otoscopy simulator was at least moderately effective in learning the mechanical techniques of otoscopy, and 66% found the simulator to

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be at least moderately effective in helping them learn to identify pathology. The majority (57%) of students reported that the otoscopy simulator was more effective than practicing otoscopy on their peers.

Conclusions: We demonstrate the utility of a novel low-cost 3D printed otoscopy simulator to teach both the mechanical skills and pathology identification necessary in performing an otoscopic exam to preclinical medical students.

Keywords
Simulation, Otoscopy, 3D Printing, COVID-19
Introduction
Otologic diseases are common in the U.S. healthcare system, accounting for over $4 billion in healthcare costs\(^1\). Common otologic complaints include hearing loss, generalized ear pain, and tinnitus, which can be related to pathologies such as tympanosclerosis, otitis media, and tympanic membrane perforations\(^3\),\(^4\). It is estimated that around 80% of all children will have otitis media, with two million cases resulting in an emergency room encounter every year\(^5\),\(^6\). Moreover, acute otitis media alone accounts for 20 million clinic visits and 10 million antibiotic prescriptions annually\(^7\). Diagnosing otologic diseases in the emergency department or clinical setting often requires otoscopy to visualize the tympanic membrane. Medical students are often dissatisfied with their level of training in otoscopy and their diagnostic accuracy is low\(^8\). Thus, training medical students in otoscopy to increase their clinical competency in correctly identifying otologic pathology is critical.

Currently, the standard approach to teach otoscopy includes two separate components. The first component involves familiarizing learners with ear anatomy and various physical exam findings through didactic teaching and the use of clinical images. The second component consists of learning the mechanical skills needed to perform otoscopy and visualize the tympanic membrane on another learner or standardized patient\(^2\). The major limitation of this approach is that the learner does not practice the mechanical skills and pathology identification simultaneously which may lead to lower self-efficacy and confidence in performing the exam and making accurate diagnoses in clinical settings. Additionally, in the context of the COVID-19 pandemic, medical schools needed to limit students’ physical exam practice of one another and keep group sizes small. Although commercially available simulators such as OtoSim allow learners to practice mechanical skills and pathology identification, these simulators can be cost-prohibitive for many institutions\(^9\).

Given limitations associated with cost of current otoscopy simulators and constraints on peer-to-peer physical exam practice and learning during the COVID-19 pandemic, we developed a low-cost 3D-printed otoscopy simulator to teach preclinical medical students the otoscopic exam, which utilizes a smartphone application that we created to display otoscopic findings. This simulator allowed students to simultaneously practice the mechanics of otoscopy and identification of a variety of common tympanic membrane pathologies. We evaluated the impact that this novel 3D-printed otoscopy simulator had on preclinical medical students’ confidence in otoscopy skills and pathology identification before and after the simulation session.

Methods
Ethics statement
This study was granted exempt status from the UC San Diego Institutional Review Board and the IRB exempt number is 801549. The IRB granted exempt status because our study gathered data from a training session that was already planned as part of the medical education curriculum. Furthermore, we included an informed consent statement in the beginning of the survey, so responding to the survey constituted written informed consent.

Simulator design
An open-source three-dimensional (3D) head file was modified using Blender (Blender Foundation, Amsterdam, Netherlands) first by cutting along 2 planes to reconfigure the dimensions. A Boolean difference was then performed to slice off the left ear and create a canal to insert an existing silicone ear (Figure 1A). Another Boolean difference was performed medial to the left ear using a 9.5-cm × 11.5-cm × 15.0-cm rectangular prism to create the housing to insert a smartphone (Figure 1B). The head was printed on an Ultimaker s5 (Ultimaker, Waltham, Massachusetts, USA) with polylactic acid, at a 0.2 mm layer height and using 10% infill. A silicone ear was purchased from Amazon (Amazon ID B086JYM9NK) and modified by attaching an ear canal which was segmented from a CT scan\(^10\). The ear was subsequently nailed onto the 3D printed head (Figure 1C).

![Figure 1. Three-dimensional otoscopy simulator and user-Interface. A, 3D rendering of the ear cut out from the head and opening for the ear canal. B, Back view of the simulator showing area to insert smartphone. C, Silicone ear attached to the otoscopy simulator. D, Screenshot from the user interface which displays various pathologies.](image-url)
Pathology display design
A user interface (UI) to display and toggle between pathologies was created using Figma version 99.0 (Figma Inc, San Francisco, California, United States), a free UI design software (Figure 1D). An iPhone screen template was used to create the UI and place the pathologies such that they lined up with the ear canal in the simulator. Additionally, arrows were added to indicate toggling between pathologies. The arrows were assigned “On Tap Triggers” to indicate switching to the next or prior pathology. A link was created and shared with each faculty instructor to open the UI on their smartphone before inserting their smartphone into the simulator. Once the UI was made, additional pathologies could be added using the same method with corresponding updates to the UI in real time.

Students were presented with one normal tympanic membrane and four pathologies (serous otitis media, acute otitis media, tympanosclerosis, and central perforation) during their use of the simulator. The images of pathology used in the simulation were identified through a literature search11,12. Students were prompted to identify the pathology before checking an answer key with the corresponding diagnosis to each image.

Simulation session
Preclinical medical students attended a 50-minute didactic on the ears, nose, and throat (ENT) exam which included instruction on how to perform otoscopy and identify common tympanic membrane pathologies. In a subsequent two-hour small group session with approximately eight students, a faculty facilitator guided students in hands-on otoscopy practice. The faculty demonstrated how to perform otoscopy on the simulator and then provided coaching and feedback to students as they practiced the exam and identified pathology independently. Using our six simulators, all 134 students were able to complete the simulation activity over two afternoon sessions (1–5pm). Small group facilitators were oriented to the simulators in 15 minutes during a just-in-time training session prior to the simulation activity.

Simulation evaluation
We evaluated the impact of the simulation activity using an anonymous survey with 5-point Likert-scale questions. Surveys were developed in accordance with the best practices for Health Professions Education survey instruments (AMEE guide No. 87) and disseminated via Qualtrics13. Surveys were emailed to students immediately after they completed the session, were anonymous, and not associated with any completion incentive.

Statistical analysis
We assigned each category on the Likert scale a numerical value (1–5) with the higher value indicating more confidence or effectiveness, and then compared how students rated these categories before and after the simulation activity using a paired t-test14.

Results
A total of 47 (35%) of the 134 students who participated in this simulation responded to our survey. A total of 28 (60%) of the participants reported that training with the 3D-printed otoscopy simulator was moderately or very effective in helping them learn the mechanical techniques of otoscopy, and 31 (66%) found the simulator to be moderately or very effective in helping them learn to identify pathology. The mean self-reported scores for confidence in performing an otoscopic exam and identifying tympanic membrane pathology, respectively, were significantly higher after the simulation activity (2.87 ± 0.87 and 2.34 ± 0.78) compared to before (1.68 ± 0.98 and 1.61 ± 0.89) (Figure 2A, 2B). We also evaluated learners’ perception of how effective the otoscopy simulator was compared to practicing otoscopy on their peers and found that 26 (57%) students reported that it was more effective.

Discussion
We demonstrate the utility of a novel 3D-printed otoscopy simulator to teach preclinical medical students both the mechanical skills and pathology identification necessary in performing an otoscopic exam. Students displayed improved confidence...
in performing the exam and identifying the pathology after utilizing the simulator. Furthermore, over 60% of the learners found the simulator to be effective in learning otoscopy and pathology recognition. This simulator adds to the educator’s toolkit for teaching otoscopy because it allows for simultaneous practice of both mechanical skills of otoscopy and identifying a pathological finding.

While OtoSim has similarly shown to improve learner confidence and increase immediate and longer-term knowledge scores in otoscopy after training, a significant drawback with this commercially available simulator is cost. One of the most advantageous aspects of this novel simulator is its low cost. The 3D-printed otoscopy simulator costs approximately $70/simulator, takes five minutes to construct after all parts are printed, and can accommodate the visualization of an unlimited number of. Additionally, in the context of the COVID-19 pandemic, this simulator allows for socially distanced in-person teaching that does not require peer-on-peer practice.

Although students’ self-report of otoscopy and pathology identification scores improved following the simulation sessions, self-reported efficacy was low overall. We hypothesize that this is because the activity was conducted with early preclinical learners who had no previous experience with otoscopy. Moreover, the simulator malfunctioned with one group of students, and it is possible that their evaluation of the simulation skewed the results. Our study is limited by a low survey response rate, and it was only conducted at a single center with one level of learner. While the simulation does not capture the true feel of working with human tissue and lacks feedback related to a patient’s discomfort, it offers an intermediate step for learning about exam mechanics and pathology, in turn preparing students for examining real patients. Furthermore, utilizing the simulator removes any concern about causing a patient pain or taking up the time of an actual person, which in general are strengths of simulation training.

In summary, our 3D-printed otoscopy simulator was effective in increasing preclinical medical students’ confidence in their mechanical otoscopy skills and identification of tympanic membrane pathology. We plan to study whether the effectiveness of this simulation improves when students practice with it longitudinally overtime and/or whether it is more impactful when used with more advanced learners (e.g. clinical medical students, residents). This low-cost approach to clinical skills teaching has wide application and low barriers to implementation.

Data availability
Underlying data
Zenodo: Otoscopy Simulator, https://doi.org/10.5281/zenodo.59329617

This project contains the following underlying data:
- Survey Data.pdf (Qualtrics report with the data from the post-training learner survey)

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Extended data
Zenodo: Otoscopy Simulator, https://doi.org/10.5281/zenodo.59329617

This project contains the following extended data:
- Otoscopy Simulator Head.stl (3D file for the otoscopy simulator)
- Otoscopy Simulator ear canal.stl (A 3D file of the ear canal)
- Otoscopy UI.docx (A file with link to the UI used for the simulator)
- Otoscopy simulator ear canal mold.stl (A 3D file containing the mold used to create silicone ear canals)

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Analysis code available from: https://github.com/spatel093/Otoscopy-Simulator-Data/projects?type=beta

Archived analysis code as at time of publication: https://doi.org/10.5281/zenodo.5932968

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References
1. Rosenfeld RM, Shin JJ, Schwartz SR, et al.: Clinical Practice Guideline: Otitis Media with Effusion (Update). Otolaryngol Head Neck Surg. 2016; 154(1 Suppl): S1-S41. PubMed Abstract | Publisher Full Text
2. You P, Chahine S, Husein M: Improving learning and confidence through small group, structured otoscopy teaching: a prospective interventional study. J Otolaryngol Head Neck Surg. 2017; 46(1): 68. PubMed Abstract | Publisher Full Text | Free Full Text
3. Asiri S, Hasham A, al Anazy F, et al.: Tympanosclerosis: review of literature and incidence among patients with middle-ear infection. J Laryngol Otol. 1999; 113(12): 1076–1080. PubMed Abstract | Publisher Full Text

4. Wahid FI, Nagra SR: Incidence and characteristics of Traumatic Tympanic Membrane perforation. Pak J Med Sci. 2018; 34(5): 1099–1103. PubMed Abstract | Publisher Full Text | Free Full Text

5. Paul CR, Higgins Joyce AD, Beck Dallaghan GL, et al.: Teaching pediatric otoscopy skills to the medical student in the clinical setting: preceptor perspectives and practice. BMC Med Educ. 2020; 20(1): 429. PubMed Abstract | Publisher Full Text | Free Full Text

6. Kozin ED, Sethi RK, Remenschneider AK, et al.: Epidemiology of Otologic Diagnoses in United States Emergency Departments. Laryngoscope. 2015; 125(8): 1926–1933. PubMed Abstract | Publisher Full Text | Free Full Text

7. Ren Y, Sethi RKV, Stankovic KM: Acute Otitis Media and Associated Complications in United States Emergency Departments. Otol Neurotol. 2018; 39(3): 1005–1011. PubMed Abstract | Publisher Full Text | Free Full Text

8. Niermeyer WL, Philips RHW, Essig GF Jr, et al.: Diagnostic accuracy and confidence for otoscopy: Are medical students receiving sufficient training? Laryngoscope. 2019; 129(8): 1891–1897. PubMed Abstract | Publisher Full Text | Free Full Text

9. Dell’Era V, Garzaro M, Carenzo L, et al.: An innovative and safe way to train novice ear nose and throat residents through simulation: the SimORL experience. Acta Otorhinolaryngol Ital. 2020; 40(1): 19–25. PubMed Abstract | Publisher Full Text | Free Full Text

10. Bracken D, Coffey C, McAvoy S: 3D Printable Myringotomy Trainer. 2020. Publisher Full Text

11. Schiller AG, Chonnaitree T, Cripps AW, et al.: Otitis media. Nat Rev Dis Primers. 2016; 2: 16063. Publisher Full Text

12. Lollar KW, Bien AG: Images in clinical medicine. Persistent Stapedial Artery Visualized through a Perforated Tympanic Membrane. N Engl J Med. 2011; 365(22): e42. PubMed Abstract | Publisher Full Text

13. Artino AR Jr, La Rochelle JS, Dezee KJ, et al.: Developing questionnaires for educational research: AMEE Guide No. 87. Med Teach. 2014; 36(6): 463–474. PubMed Abstract | Publisher Full Text | Free Full Text

14. Sullivan GM, Artino AR Jr: Analyzing and Interpreting Data From Likert-Type Scales. J Grad Med Educ. 2013; 5(4): 541–542. PubMed Abstract | Publisher Full Text | Free Full Text

15. Lee DJ, Fu TS, Carrillo B, et al.: Evaluation of an otoscopy simulator to teach otoscopy and normative anatomy to first year medical students. Laryngoscope. 2015; 125(8): 2159–2162. PubMed Abstract | Publisher Full Text

16. Xu J, Campisi P, Forte V, et al.: Effectiveness of discovery learning using a mobile otoscopy simulator on knowledge acquisition and retention in medical students: a randomized controlled trial. J Otolaryngol Head Neck Surg. 2018; 47(1): 70. PubMed Abstract | Publisher Full Text | Free Full Text

17. spatel093: spatel093/Otoscopy-Simulator-Data: Otoscopy Simulator (v3.1). Zenodo. 2022. http://www.doi.org/10.5281/zenodo.5932968