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The 3-Dimensional Temporal Bone Dissection Manual: Operable Stepwise Models for Teaching Otologic Surgery

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Abstract

Deconstructing surgeries into steps and providing instructions with illustrations has been the staple of surgical textbooks for decades. However, it may be difficult for the novice surgeon to interpret 2-dimensional (2D) illustrations into 3D surgeries. The objective of this study is to create operable models that demonstrate the progression of surgery in 3D and allow for mastering the final steps of the operation first. Mastoidectomy was performed in a stepwise fashion to different end points on 5 identical 3D-printed temporal bone models to represent 5 major steps of the operation. The drilled models were computed tomography scanned and the subsequent images were used to create 3D model copies of each step. This is the first study to demonstrate that it is possible to create, scan, and copy stepwise, operable, patient-specific 3D-printed models, which the trainee can both reference as a 3D dissection guide and can operate on repeatedly and in any order.

Keywords

3-dimensional, dissection manual, instructional scaffolding, mastoidectomy, operable models, residency training, stepwise models, task deconstruction, temporal bone

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Stepwise training is a mainstay technique of surgical education. For example, operative textbooks and dissection manuals break down surgeries into smaller steps that are put together to demonstrate the progression of the surgery.[1] A procedure can be broken down into simpler tasks (task deconstruction) and then appropriate instruction is made available to guide the novice (instructional scaffolding).[2,3]

We propose a novel use of 3-dimensional (3D) models in surgical training: stepwise models that are operable, both to demonstrate an unfolding operation as a 3D dissection guide, but also to allow for practice of the operation, with the option to practice any specific step repeatedly and in any order. The objective of this study was to develop and pilot test a process for creating reproducible stepwise surgical 3D models that are patient and surgical educator specific. The operation chosen for proof of concept was pediatric mastoidectomy.

Methods

Institutional review board approval was obtained at the University of Pittsburgh Medical Center. Using the House Institute Temporal Bone Dissection Guide as the 2D reference to complement the 3D models,[1] 5 main surgical steps for mastoidectomy were selected for the stepwise models. Step 1 was the removal of cortex and cavity saucerization. Step 2 was the identification of the sigmoid sinus and middle fossa dura plate. Step 3 was entering the antrum. Step 4 was completing the basic mastoidectomy. Step 5 was drilling the facial recess.

An operable pediatric temporal bone 3D model was used as the starting model by which to create the stepwise models. The method used to create and print the model was developed and tested by the authors for use in pediatric mastoidectomy and middle cranial fossa

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surgery, described in detail in the literature.[4-7] Briefly, Digital Imaging and Communications in Medicine (DICOM) images from a 0.625 mm axial temporal bone computed tomography (CT) scan of a 7-year-old patient were segmented to create a model which was then printed using a desktop stereolithography 3D printer (Formlabs Form 2) using white acrylic resin (Formlabs white resin version 2). The hollow cavity corresponding to the facial nerve was filled with yellow paint and sealed. The sigmoid plate was painted blue and the tegmen was painted light red. **Figure 1** demonstrates the finished, undrilled 3D-printed model.

Five copies of the undrilled starting model were printed in preparation for drilling by an attending neurotologist in a step-by-step fashion. The first copy was drilled to reflect step 1, the second was drilled to reflect step 2, and so on until there were 5 stepwise models reflecting the attending's progression through the operation.

Once drilling was completed, the stepwise models were CT scanned using 0.625 mm axial reconstructions in a soft tissue kernel (**Figure 1**). High radiation dose CT parameters including 80 kVp, a pitch of 0.5 and 600 mAs were used to maximize image quality. The DICOM images were obtained and uploaded into a free software program (3D Slicer,[8] https://www.slicer.org) and prepared in the same manner as the original model. The stepwise models were printed, again using the Formlabs 2 printer, and painted. **Figure 2** demonstrates the original models alongside the copies.

Results

The average segmentation time including segmentation proofing and manual segmentation was 60 minutes with an average print time of 5.0 hours per model. The average postprocessing time, including curing the resin with UV light, was 1.5 hours. The resin cost per model averaged $10.

Figure 3 demonstrates CT images of the scanned models. The material was uniformly dense on CT, with air-filled spaces and the paint-filled facial nerve canal clearly identified. This allowed for the creation of 3D models based on the scanned model CTs for each step. When comparing the stepwise printed models to the originals drilled by the attending, the topographies of the copies were slightly smoother but the major bony characteristics were well preserved as demonstrated in **Figure 3**. When superimposing the copies' segmentation contours onto the original patient CT scan, there was excellent overlap between the stepwise models, with significant separation only in the mastoid, corresponding to the different amounts of drilling for each step.

Discussion

This is the first study to develop and pilot test a process for creating reproducible stepwise surgical 3D models that are patient and surgical educator specific. We demonstrate that this is a feasible and successful process. The attending surgeon can record his or her own completion of an operation, in as few or as many steps as he or she plans, and create copies of each step. The progression of surgical steps as performed by the attending is successfully captured and can be recreated through an unlimited number of copies for inexpensive practice by trainees.

This study demonstrates a novel ability to translate 2D dissection manuals into 3D learning tools. Trainees

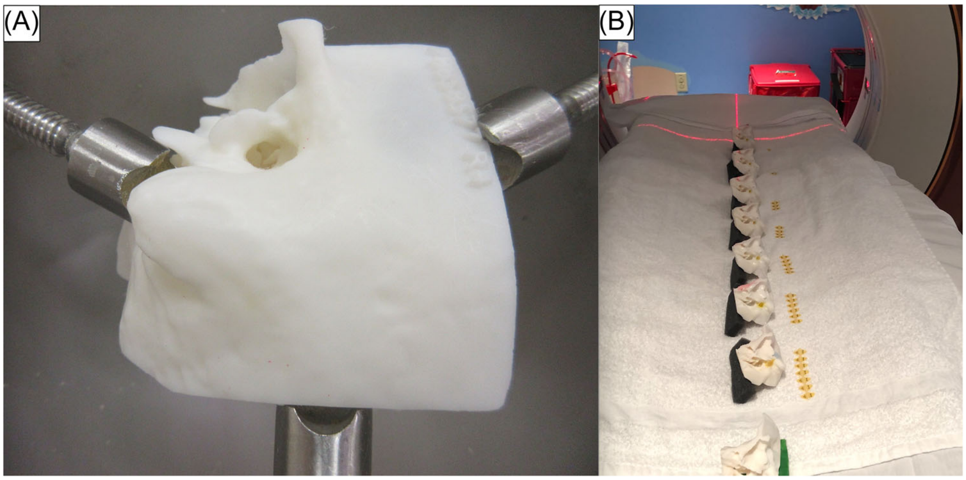

Figure 1. Pediatric temporal bone model is drilled into multiple stepwise models. (A) A photo of the undrilled 3D-printed temporal bone model created from a CT scan of a 7-year-old patient. (B) Once the stepwise models were created by the attending neurotologist, they were CT scanned. Multiple models could be scanned at once and differentiated from each other by yellow CT markers. 3D, 3-dimensional; CT, computed tomography.

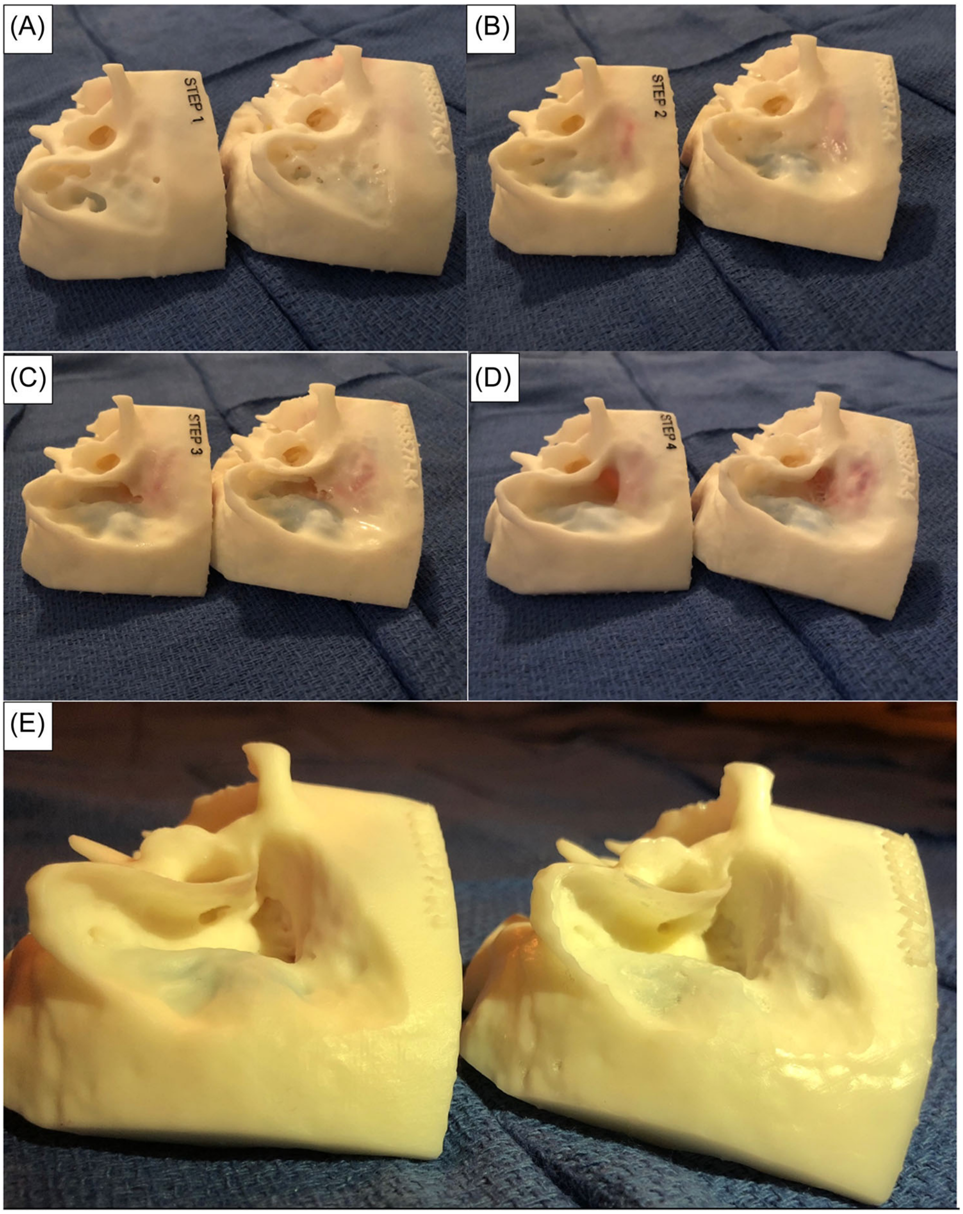

Figure 2. Drilled models alongside the 3D-printed copies. The drilled original models are on the right side while the copies made from CT scans of the originals are to the left. (A) Step 1: Removal of cortex and cavity saucerization. (B) Step 2: Identification of the sigmoid sinus and middle fossa dura plate. (C) Step 3: Entering the antrum. (D) Step 4: Completing the basic mastoidectomy. (E) Step 5: Drilling the facial recess. 3D, 3-dimensional; CT, computed tomography.

can refer to the models as they read a dissection manual. They can appreciate in 3D the relationships of structures and the progression of the operation. The models can be held, turned, and examined under the microscope. As they drill, they can refer to the models to see what the next step completed looks like.

In addition to using the stepwise models as a 3D guide, the models themselves can be operated on. Trainees can drill the models and do so repeatedly until the individual task component is mastered. The models can be practiced in any order, with the possibility of mastering a subsequent step before completing an initial step (**Figure 4**).

Conclusion

This study demonstrates a novel use of 3D models: creating stepwise models that are operable, both to demonstrate an unfolding operation as a 3D dissection guide, but also to allow for practice of the operation, with the option to practice any specific step repeatedly and in any order.

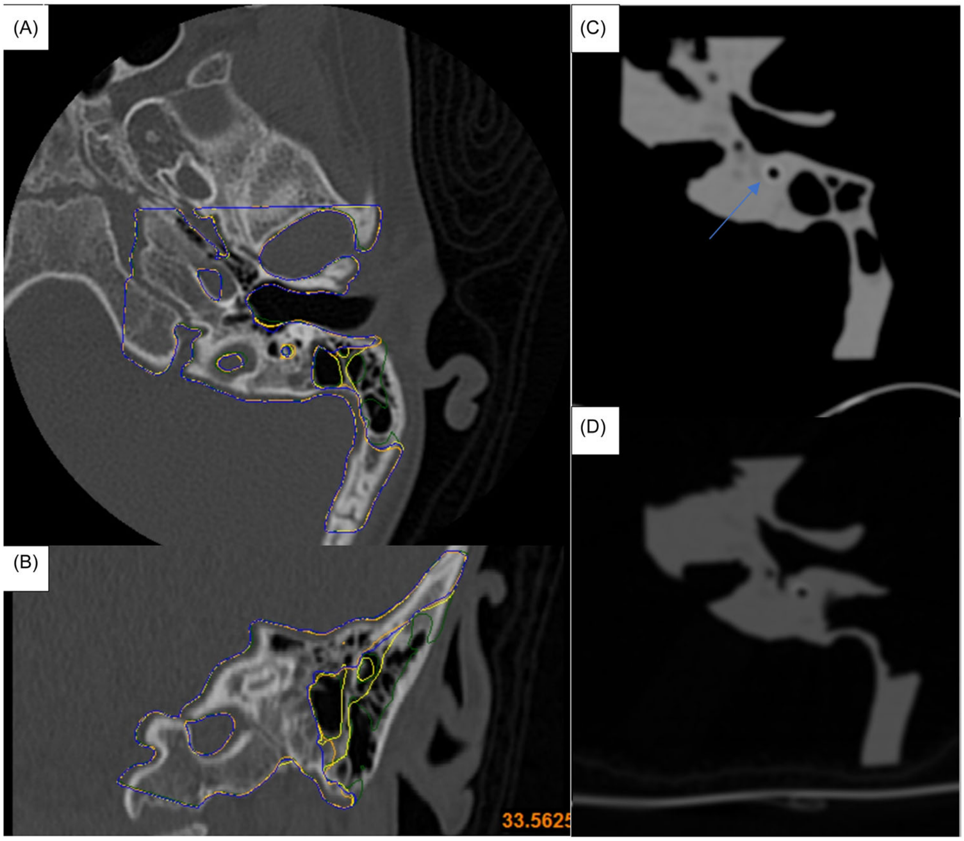

Figure 3. Segmentation lines from the copy models overlaid onto the patient CT Scan. Segmentation lines from the copy models are overlaid onto the original axial (A) and coronal (B) patient CT scan. Green is step 1, yellow is step 2, orange is step 3, and blue is step 4. (C) CT scan of the drilled step 1 model. While the photoacrylic material is a uniform color on CT, the topography and hollow cavities are preserved. Note the brighter density of the facial nerve canal due to paint (arrow). (D) Axial CT scan of the drilled step 4 model. CT, computed tomography.

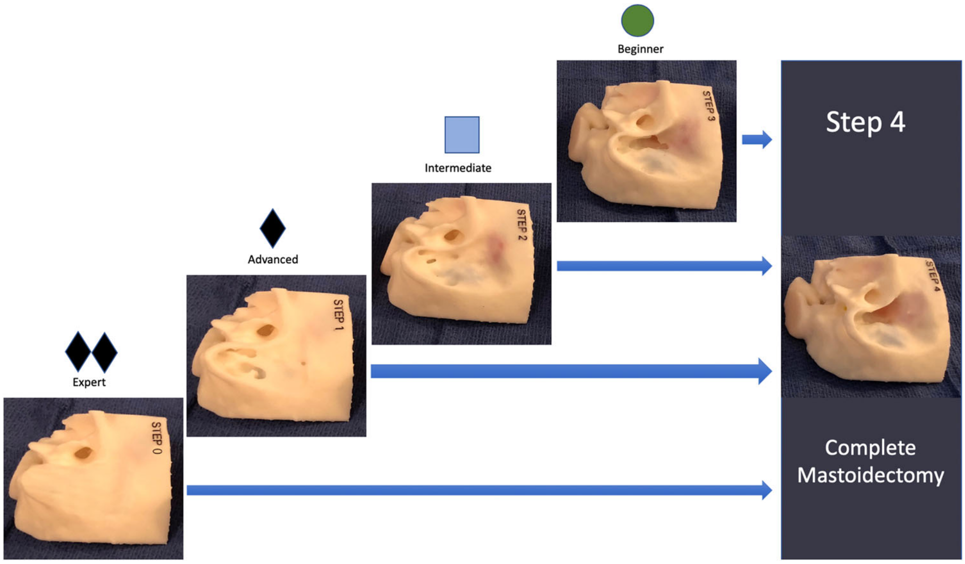

Figure 4. Stepwise operable models allow for unique training options. With a customizable and operable 3D manual, the trainee can both visualize the upcoming steps in 3D as well as practice any step repeatedly. There is the opportunity to master the last steps of the operation before the first steps, such as in this demonstration where the beginner first practices steps 3 to 4, before advancing to practice steps 2 to 4, and so forth. 3D, 3-dimensional.

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Author Contributions

Monika E. Freiser, design of the work, analysis, and interpretation of data, authorship of the manuscript, final approval, agreement to be accountable; **Michael Magnetta**, design of the work, analysis, and interpretation of data, authorship of the manuscript, final approval, agreement to be accountable; **Anish Ghodadra**, design of the work, analysis, and interpretation of data, authorship of the manuscript, final approval, agreement to be accountable; **Johnathan E. Castaño**, design of the work, analysis, and interpretation of data, authorship of the manuscript, final approval, agreement to be accountable; **Noel Jabbour**, design of the work, analysis, and interpretation of data, authorship of the manuscript, final approval, agreement to be accountable.

Disclosures

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