Training for Skull Base Surgery with a Colored Temporal Bone Model Created by Three-Dimensional Printing Technology

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■ OBJECTIVE: **A 3-dimensional temporal bone model for skull base surgical training was reconstructed via the use of a selective laser sintering technique, which is one of the 3-dimensional printing technologies.**

■ METHODS: **The temporal bone model was created in 2 pieces to remove powder material in the mastoid air cells and to place dye into the semicircular canal and the Fallopian canal.**

■ RESULTS: **The powder material was minimal, and the decisive structures were identified in color.**

■ CONCLUSIONS: **This artificial model will pave the way to a "new era" in surgical training and medical education.**

INTRODUCTION

Laboratory training is essential before the clinical application of microsurgical techniques because the surgeon's individual skill plays a crucial role in determining patient outcomes.[1,2] Donaghy[3] suggested that "a first experience has no place in the operating room." Surgical training, which synchronously results in acquiring knowledge of anatomy, is the most effective way to shorten the learning curve in microsurgery.[4] There is no doubt that cadaveric dissection is the gold standard to learn about anatomy and surgical approaches, including the technique of drilling; however, it should be noted that surgical training with cadavers is prohibited in some countries. In addition, human cadavers always carry a risk of transmitting infectious agents.

We created a synthetic skull model that closely resembles a real skull.[5] The model is appropriate for the training of skull base drilling because of its reproducibility of precise anatomy and tactile feedback. Furthermore, its thermal stability allows the trainees to use a high-speed drill. This model, however, has 2 major limitations: 1) the powder in the mastoid air cells impairs identification of the mastoid antrum, and 2) the homogeneous, whitish color makes it difficult to distinguish the semicircular canals. The aim of this study is to overcome the shortcomings of this previous model and to develop a more-suitable training model for temporal bone drilling.

MATERIALS AND METHODS

Creation of Colored Temporal Bone Model

The powder comprises a synthetic resin (polyamide nylon) and an inorganic filler (glass beads) that accumulates in layers when the additive manufacturing technique of selective laser sintering (SLS) is performed. A comprehensive description of the powder composition and the SLS technique has been reported previously.[5] The digital imaging and communication in medicine data of the whole skull was obtained with an Aquilion 64 (Toshiba Medical Systems, Tochigi, Japan) multidetector-row computed tomography (MD-CT) machine. After the temporal bone was digitally carved out from the reconstructed whole skull, part of the temporal bone was cut into a "W" shape on the computer with Mimics (Materialise Japan Co., Ltd., Yokohama, Japan), such that the semicircular canals and the Fallopian canal were exposed. Because "V"- or "L"-shaped cuts had been an ineffective method previously to put dye into all of the semicircular canals, the "W" cut was selected.

Key words
- Education
- Mastoidectomy
- Selective laser sintering
- Skull base surgery
- Surgical training
- Temporal bone model
- 3D printing

Abbreviations and Acronyms
MD-CT: Multidetector-row computed tomography
SLS: Selective laser sintering
3D: Three-dimensional
2D: Two-dimensional

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The model was the produced in 2 pieces by the SLS method with a layer pitch of 0.1 mm (Figure 1A). Powder inside the mastoid was removed by an air duster, and then a pink dye and a yellow dye were placed in the semicircular canals and the Fallopian canal, respectively. A dye consisting of plastic liquid color was put on the superior and posterior semicircular canals and the Fallopian canal by the use of a small writing brush, because the insides of these canals were exposed directly on the cutting plane (Figure 1B–C). In contrast, the plastic liquid color was run into the lateral semicircular canal with a tiny interdental brush, because only the orifices of the canal were exposed on the plane. Then, both pieces were merged with glue. The medial side of the model was colored in beige or covered by a silicone membrane to resemble the dura mater. The grooves of the sigmoid sinus and the superior petrosal sinus were colored in blue or filled with blue silicone.

Training for Temporal Bone Drilling

The colored temporal bone model was drilled with a high-speed drill under an operative microscope. In addition, a half skull model, which excluded the temporal bone, also was created so that the trainee could repeatedly perform the mastoidectomy by exchanging that part of the temporal bone. The skull frame was matched with the temporal portion of the model.

Validation of Accuracy

The temporal bone model was scanned by MD-CT. The accuracy was investigated by fusion of the original temporal bone and the model using a Ziostation2 workstation (Ziosoft Inc., Tokyo, Japan).

RESULTS

The temporal bone model can be drilled with a high-speed drill without melting any important structures. The feeling of the drilling is closely similar to drilling actual temporal bone. Powder was observed rarely inside the mastoid (Figure 2).

Proceeding with the mastoidectomy results in a good visualization of the semicircular canals (pale pink structures) and the Fallopian canal (yellow rod-like structure) (Figure 3A). Although the magnified view of the semicircular canals and the Fallopian canal revealed the bonded line of the cut surface, this merged line did not disturb the training of drilling (Figure 3B).

Because of complete multiplication of the model by the SLS technique, the stepwise procedures can be explained by use of the model as an educational and instructional tool during a training course (Figure 4). In addition, the long shelf life of the model enables the trainee to check the structures and procedures in incremental steps without requiring oversight from an instructor. In addition, the trainees can perform the mastoidectomy procedure on their own by checking each step of the procedure against prepared models.

The created temporal bone (Figure 5A) was fitted to the outer frame of the half skull model excluding the temporal bone part (Figure 5B). The combination of both models formed the caudal half of the lateral skull base (Figure 5C).

The accuracy of the model was confirmed by the use of an image fusion technique between the actual temporal bone and the model scanned by MD-CT (Figure 6). Differences between the images of the length of the semicircular canals and the width of the Fallopian canal and the sigmoid sinus were exiguous, within the range of submillimeters (Table 1).

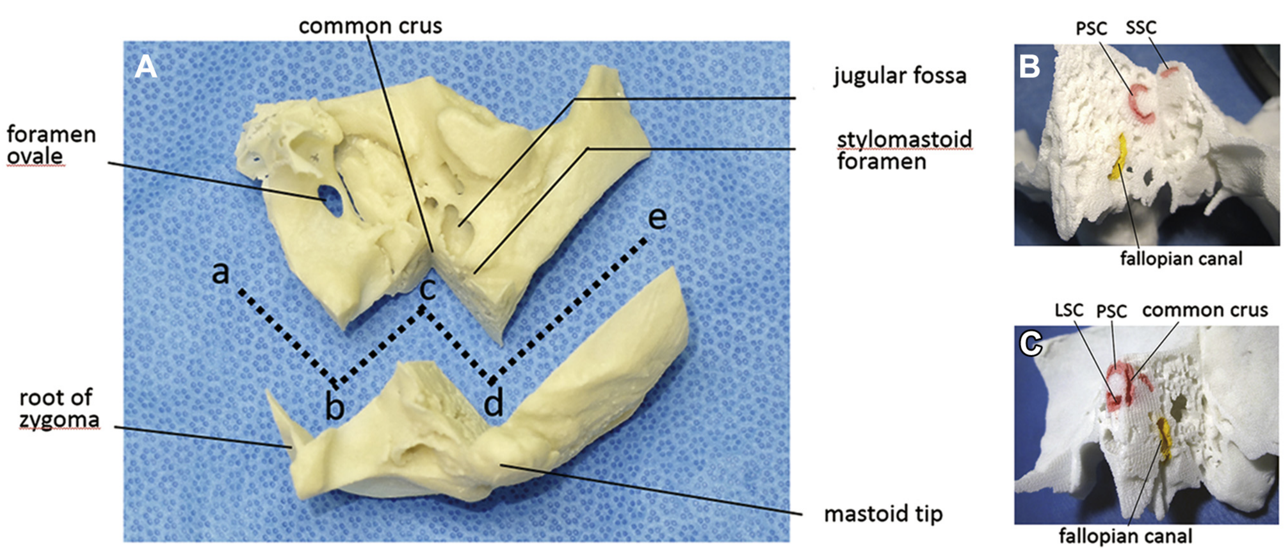

Figure 1. The model of the temporal bone part before bonding. (**A**) The temporal bone part on the right side is created in 2 pieces. The cutting plane is designed in a "W" shape. The inferior view of both parts is shown. The line a-b is required to keep the root of the zygoma intact in the lateral view. The posterior semicircular canal (PSC) and the superior semicircular canal (SSC) are exposed on the surface cut by the line b-c. The Fallopian canal exists at the center of the plane cut by the c-d line. The d-e line is necessary to remove the powder in the mastoid air cells. Point b: medial to the root of zygoma, Point c: common crus, Point d: medial to the mastoid tip. (**B**) The cutting surface includes the semicircular canals and the Fallopian canal. A pink and yellow dye is put inside these structures, respectively. (**C**) The cutting surface of the opposite side includes the superior, posterior, and lateral semicircular canals, and the Fallopian canal. LSC, lateral semicircular canal.