3-Dimensional Middle Ear Model for Stapedectomy

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***Abstract*—Stapedectomy is a surgery that removes an immobilized footplate and replaces it with a prosthetic piston that re-enables hearing. Because it is an intense and delicate procedure, which requires surgical residents to continually practice to maintain their skills. Currently, the only available model is to use cadaver, which does not give an appropriate environment for residents and doctors to practice because of the postmortem tissue changes, limited availability, and high costs. In order to provide the opportunity to practice multiple times, we developed a life-size middle ear model, composed of 3D-printed cartridge that enables facile and economical replacements. The 3D-printed middle ear surgical model delivers a real-time feedback through force sensors, allowing replication of this surgical procedure.**

Keywords—stapedectomy; middle ear; ossicular chain; facial nerve; surgical model; force feedback

I. INTRODUCTION

Stapedectomy, a surgery removing stapes and replacing the removed stapes with a prosthetic device, is a very delicate and challenging procedure because it deals with the ossicular chain, which contains the smallest bones of all the bone within the human body [1] (Fig. 1B). The failure of the surgery can result in multiple complications such as hearing loss, vertigo, perforation of the tympanic membrane, nystagmus, perilymph fistula, and labyrinthitis [2]. The opportunities for novice surgeons to practice this delicate procedure are limited prior to working with live patients. Currently, the practices are performed on cadaver temporal bones, which are subject to numerous problems. Cadaver models are not reusable and do not provide real-time feedback to the surgeon. In addition, cadaver has postmortem tissue changes, which alter the surgical experience, limited in availability and are costly to obtain [3]. Since the outcome of surgery is correlated to the surgeon's experience, a model utilizing 3D printing from micro-computed tomography of a human temporal bone (Fig. 1A) with pressure sensors will be beneficial to surgeons for training and will provide wide and easy accessibility to improve their skills. The purpose is to design a life-size middle ear surgery model for stapedectomy that provides immediate feedback via pressure sensors to allow for multiple training sessions for doctors, residents, and medical students.

II. METHODS

From a micro-computed tomography of a temporal bone of an otosclerosis patient, a 3D model of middle ear was modified and generated using Slicer 4.4, MeshLab 1.3, and Meshmixer 3.0 software. The middle ear space was created with a Makerbot, and the external ear canal and the ossicular chain with the footplate was printed with an Objet350 Connex. Cartridge and cassette were constructed in computer-aided design (CAD), where cartridge includes ossicular chain with a handle for easy replacing and cassette has the groove for sliding in and holding the cartridge (Fig. 2). The facial nerve was integrated into the cassette, using a wire. When the nerve is touched during the simulated surgery, a loud noise is made to warn the surgeon of potential damage to the nerve. In addition, a pressure sensor (SEN-09673, Interlink Electronics) was placed below the footplate to measure the maximum and cumulative force during fracture of posterior crus of stapes, fenestration of footplate, and prosthesis placement, which are critical steps during the stapedectomy procedure. The force will be monitored and excessive levels of force will be indicated by a red LED. The sound system and LEDs provide immediate feedback to novice surgeons during the surgical procedure. In addition, a mini video camera was incorporated in the design so that the practice surgery can be viewed by others and recorded during training sessions for assessment purposes. The exterior shell, which is the size of human head, was built with PVC to store the electronics, camera, cassette, and cartridge, while providing a typical approach for the surgeon through the ear canal.

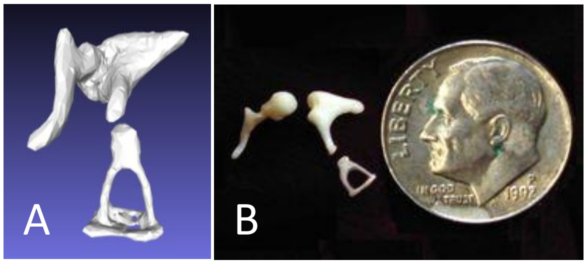

Fig. 1. A) Rendered ossicular chain from the micro CT scan from temporal bone of otosclerosis patient. B) Scale of the ossicular chain compared to a dime.

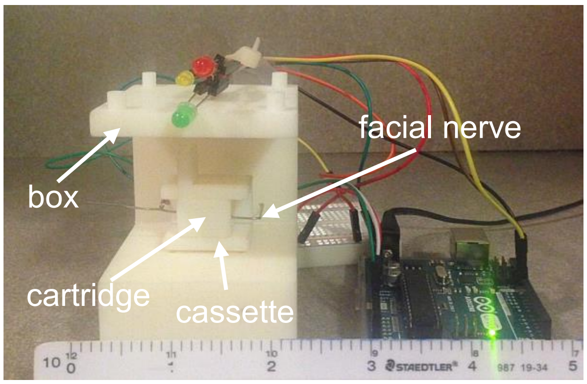

Fig. 2. Components of simulation model with the cartridge containing the ossicular chain (not visible). The cassette positions the cartridge and facial nerve. The box interfaces with the exterior shell and contains the force sensor (not visible) under the cassette. On the right side, Arduino and breadboard will be installed with the model and connected to LEDs.

III. VALIDATION TESTING

The experienced doctors and residents, in Temple University Hospital, will test the middle ear device by running through the actual surgery procedure. Each will receive an evaluation sheet to give feedback on the device and the model will be modified based on their feedback.

IV. RESULTS

The ossicular chain, which consists of malleus, incus, and stapes, is well replicated from the CT scan. The acceptable force when making fenestration on the footplate is 6.60 N [4]. When the user is applying force greater than 6.60 N, the yellow LED light turns on, and the red LED light follows for even greater force range. Since even the slightest touch on the facial nerve can lead to a serious nerve injury, the red LED light lights up for 10 seconds along with a loud beep sound to warn the user. As expected, the pressure sensor gives the user an immediate feedback.

V. CONCLUSIONS

The 3D middle ear model is beneficial for the medical students and residents to develop the technical skills needed for the stapedectomy. Through the continuous usage of the model, the users showed improved performance over time. Using 3D printer allowed affordable model reproduction and more accessibility for numerous otology institutions.

REFERENCES

[1] Bell, Brett, Stefan Stankowski, Benjamin Moser, Vidina Oliva, Christof Stieger, Lutz-Peter Nolte, Marco Caversaccio, and Stefan Weber. "Integrating optical fiber force sensors into microforceps for ORL microsurgery." In *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, pp. 1848-1851. IEEE, 2010.

[2] Al Husban, Hassan. "Outcome of management of otosclerosis by stapedotomy compared to stapedectomy in a jordanian population." *Oman medical journal* 28, no. 1 (2013): 36.

[3] Landry, Thomas G., James W. Rainsbury, Robert B. Adamson, Manohar L. Bance, and Jeremy A. Brown. "Real-time imaging of in-vitro human middle ear using high frequency ultrasound." Hearing research 326 (2015): 1-7.

[4] Rothbaum, Daniel L., Jaydeep Roy, Gregory D. Hager, Russell H. Taylor, Louis L. Whitcomb, Howard W. Francis, and John K. Niparko. "Task performance in stapedotomy: comparison between surgeons of different experience levels." *Otolaryngology—Head and Neck Surgery* 128, no. 1 (2003): 71-77.