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Virtual 3-Dimentional Models of Abnormal Cochleae for Cochlear Implantation

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Abstract

Introduction: The scarcity of providing real human specimens, yet increase in demand of temporal bone training, gives rise of virtual model of temporal bone. On top of that, we produced an accurate live size 3D model of Mondini and common cavity utilising high resolution computed tomographic scans (HRCT – 0.5mm slices).

Mythology: Practicing otological surgeons to assess and validate the accuracy of these models via surgery and anatomical landmarks on models.

Result: These 3D models scored high (between 3.83 - 3.75) on anatomical and acoustic realism.

Conclusion: Virtual 3D models can be an alternative for temporal bone dissection training especially for abnormal cochlear of Mondini and common cavity.

Keywords: *3D printing model; cochlear implant; Mondini; Common cavity.*

Introduction

The skills of ear surgery are best developed by practicing dissection of human temporal bones. However, not all trainees have this opportunity because of scarcity of cadaver bones available for training. Teaching models today allow procedures to be simulated for both trainees and practicing surgeons, and these models are especially useful if cadavers are difficult to obtain.

Rapid prototyping (RP) or three-dimensional (3D) printing machines have been available since 2000 to convert 3D computer aided drawings into 3D objects made from powder or other materials. Rapid prototype models are printed in layers from the base upwards until the entire object has been created.

In medical field, rapid prototype models have been used by neurosurgical, maxillofacial and orthopaedic speciality to plan surgery and for training purposes. In otorhinolaringology, temporal bone models of normal cochlea and congenital aural atresia had been produced in the past for similar purpose.

We have produced models of Mondini and common cavity with this technology in view of teaching and training otorhinolaringologists to perform cochlear implantation in these abnormalities.

Methodology

High-resolution (0.5 mm slices) axial computed tomographic (HRCT) scans of 2 individuals with Mondini and common cavity cochlear abnormality were obtained in digital imaging and communications in medicine (DICOM) format. From the scanned data, bony structures were automatically separated from soft tissue based on differential grayscale pixel values. The structures within the temporal bone (sigmoid sinus, facial nerve, ossicles, semicircular canals, cochlea) were then manually drawn (outlined) on each HRCT image.

The CT scan dataset was then converted into a 3D stereolithography file format. The structural data for the biomodel was then read by an industrial rapid prototyping machine (Rapid prototype machine-Stratasys Connex 500), which then reproduced a physical model of the temporal bone using Vero White Plus Full Cure 835 and Tango Plus Full Cure 930. This process was performed repeatedly, one thin layer at a time, until a 3D model was constructed, the printing performed continuously as a 2-piece construction which was divided at the level of internal auditory meatus. Colours were added to common cavity model to delineate the facial nerve.

These models were then left to dry and subsequently syringing method was used to remove residue from the model. Ten otologists with at least 5 year experience in the field were recruited to evaluate the completed Mondini and common cavity RP models respectively. These otologists were asked to drill the artificial bone using mastoide- ctomy instruments and microscope. Furthermore, they inserted a special cochlear implant which was produced by Med-El. The implant was crafted with designated electrodes. The surgeons then completed a rating survey which comprised of anatomic and acoustic realism. Surveys were rated based on a scale of 1- 5, (1- not accurate and 5- most accurate).

Result

Anatomical Realism [Refer Figure 1]

Cortical bone scored highest in anatomical realism with 3.83, followed by overall morphology and stapes, 3.67 and 3.66 respectively for Mondini model. The other structures such as facial nerve, facial recess, cochleae and sigmoid sinus received average scores between 2.67 - 2.8. Common cavity model scored highest for mastoid air cell and antrum with score of 3.75 each, followed by cortical bone 3.5 and 3.25 score for overall morphology, facial recess, posterior tympanotomy and round window niche.

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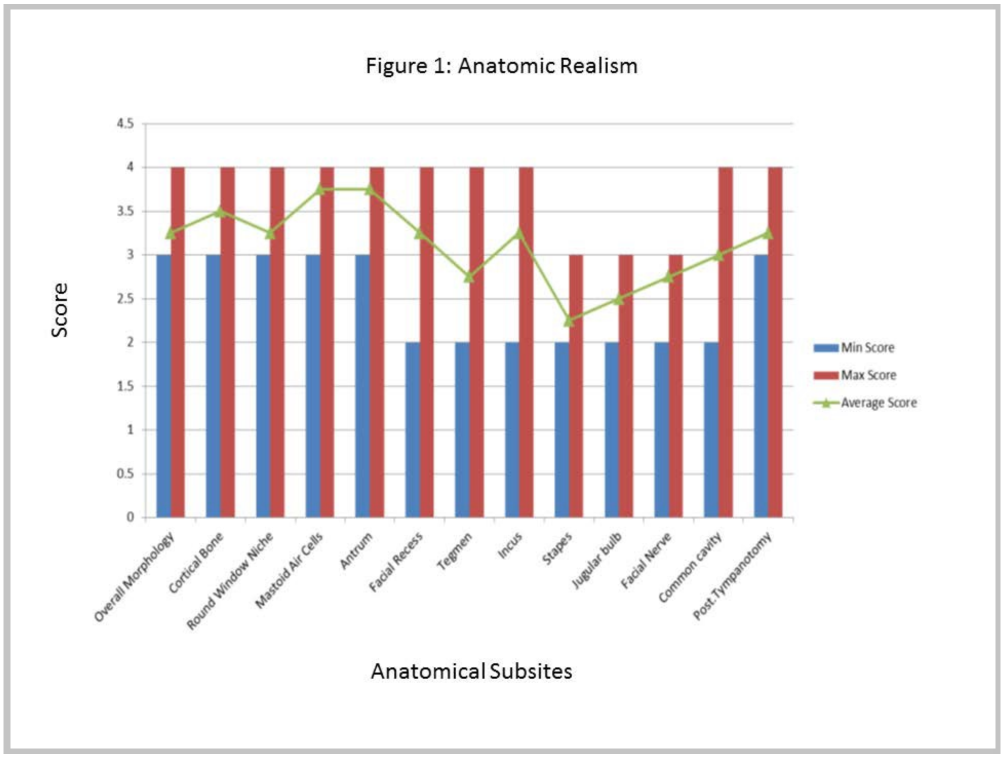

Figure 1: Impression of the presence in the virtual world of the human's head anatomy in our OR with navigation and manipulation (VS) with virtual anatomic non-existing virtual environment.

Acoustic Realism [Refer Figure 2]

Facial recess, cochlea and semicircular canal had lower ratings with score below 3.0 compared to lateral structures, cortical bone and mastoid air cells with scores between 3.33 and 3.63.

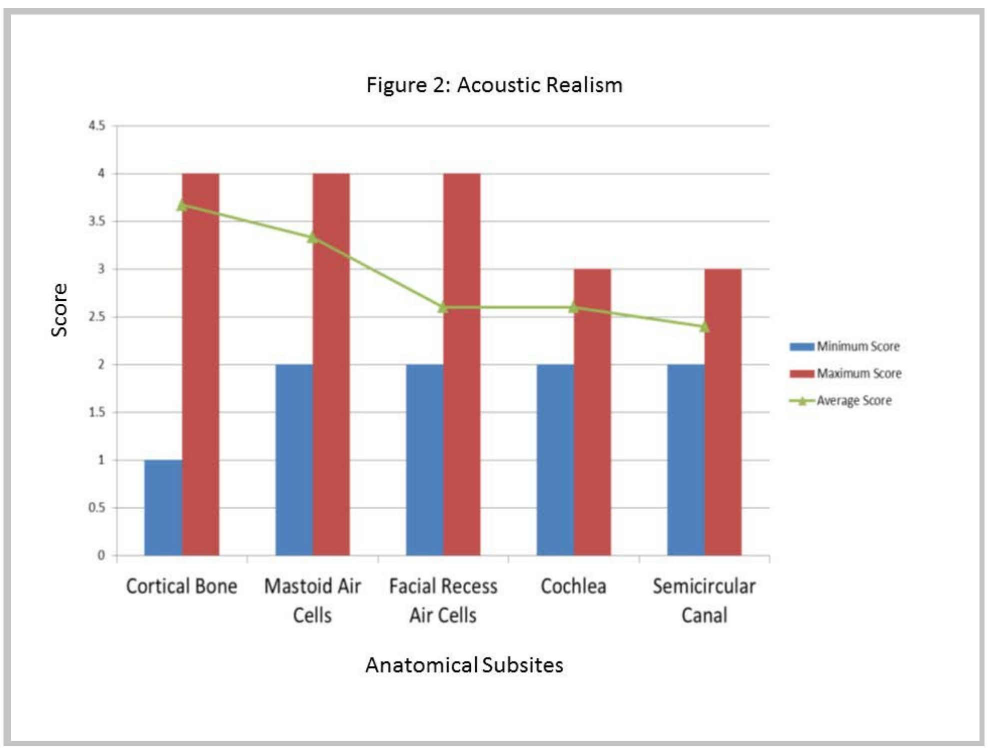

Figure 2: A graph revealed that cortical bone had good score for the acoustic realism.

Discussion

Rapid prototyping has gained popularity in medicine in various specialities such as orthopaedic, maxillofacial and neurosurgery, for purpose of teaching and training. This would benefit students and young trainees in knowledge of anatomy and surgical skills. Surgical training for trainees is a challenge due to limited opportunity regardless of live patients or cadavers which are mainly attributed to ethical and cost issues. It has also become important in planning for an operation prior to the real surgery which is widely practised by maxillofacial [1, 2, 3, 4]. Artificial models are found to be easily available, easy for handling and reasonably of low cost. Temporal bone models allow structured training, with similar pathology and anatomy in each model, in contrast to cadaveric models which could have anatomical variations [5, 6, 7].

In the last decade, many temporal bone models have been developed with normal anatomy for temporal bone dissection, middle ear implant, cochlear implant and skull base surgery. Models were made from powder and liquid resin materials, cured with laser using prototype technology. Some of these models had cavities injected with coloured acrylic material to define anatomical structures [8, 9, 10, 11].

In this study, we have produced temporal bone models of abnormal cochleae, Mondini and common cavity with successful insertion cochlear implant. Post insertion, x-ray was taken to confirm the placement of cochlea implant within the cavity [Figure 3]. There were positive responses by the participating surgeons in regards to the models as a teaching tool for temporal bone dissection and cochlea implantation.

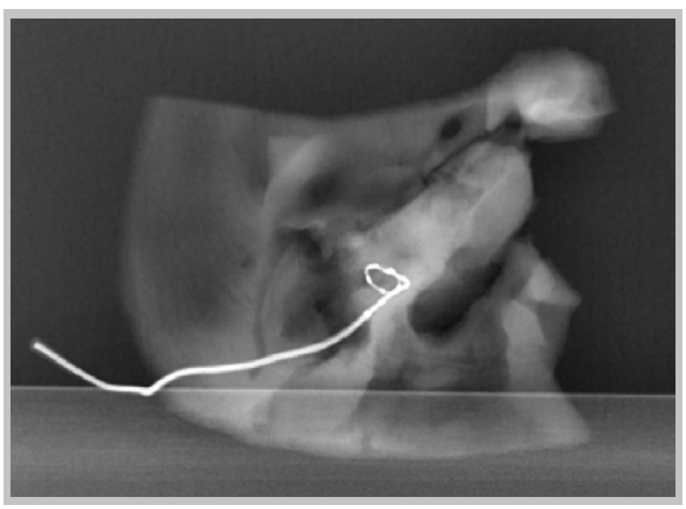

Figure 3: An x-ray of temporal 3D model after cochlear implantation showed the electrode within the cavity.

The entire model for Mondini and common cavity were printed with the same ratio of rigid and rubber material from base upwards, hence the identification of structures such as ossicles, facial nerve, semicircular canal and cochlea were based on density, shape and sound on drilling. Our models scored highest for anatomical structures as outer and middle ear structures were able to be identified, the model was dissected in the same manner as a real bone using cutting burr of high speed drill and the feel of drilling was also close to human bone. Cortical bone scored highest with 3.83 followed by overall morphology and stapes, 3.67 and 3.66 respectively for Mondini model. The other structures such as facial nerve, facial recess, cochlea and sigmoid sinus received average scores between 2.67-2.8. Common cavity model scored highest for mastoid air cell and antrum with score of 3.75 each, followed by cortical bone 3.5 and 3.25 score for overall morphology, facial recess, posterior tympanotomy and round window niche.

Drilling of mastoid air cells and finding the facial nerve was far more difficult than in real bone, due to residue material within air cells and cavity resulting in sticky material when bone dust comes in contact with irrigation water.

Mick et al. and Suzuki et al. both had reported, bone dust upon drilling their models were stickier and fused texture compared to human temporal bone dust. It was harder to remove upon drilling and irrigation. This was attributed to one piece printing process. Our models also faced the similar problem at the level of air cells and common cavity, though it was constructed in two pieces at the level of internal auditory meatus [3,12,13,14,15] A malleus was not seen in common cavity model though it was present in the patient and HRCT. Another limitation according to response given by participants was difficulty in finding facial nerve in Mondini model as the colour of the nerve is similar to the surrounding structures. We used grey coloured material for facial nerve in common cavity model which made identification easier. Both models were said to have softer consistency upon drilling compared to human bone.

In both models, the round window niche was identified and the insertion of cochlear implant electrode was similar to insertion of electrode into human bone. Anatomic structures and consistency of model have room for improvement with availability of other materials for 3D printing [16,17,18,19].

Acoustic realism for facial recess, cochlea and semicircular canal had lower ratings with score below 3.0 compared to lateral structures, cortical bone and mastoid air cells with scores between 3.33 and 3.63.

Conclusion

Temporal bone models with Mondini and common cavity can be produced using the 3D printing technique. These models provide successful temporal bone dissection and cochlear implantation for otology trainees; therefore they are good alternative tools for cochlear implant practice in abnormal cochleae.

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