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Developing 3D Printed Temporal Bone Models for Otological Surgery Training and Simulation

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INTRODUCTION

Three-dimensional Printing (3D Printing), or Additive Manufacturing, is an advanced fabrication technique that can construct 3D objects from a 3D digital model. This is usually done through an automated layer-wise deposition of material. Generally, a 3D object is put through a “slicing” software that generates a G-Code file which contains the instructions for printing. These instructions are then read by a 3D printer which then constructs the model.

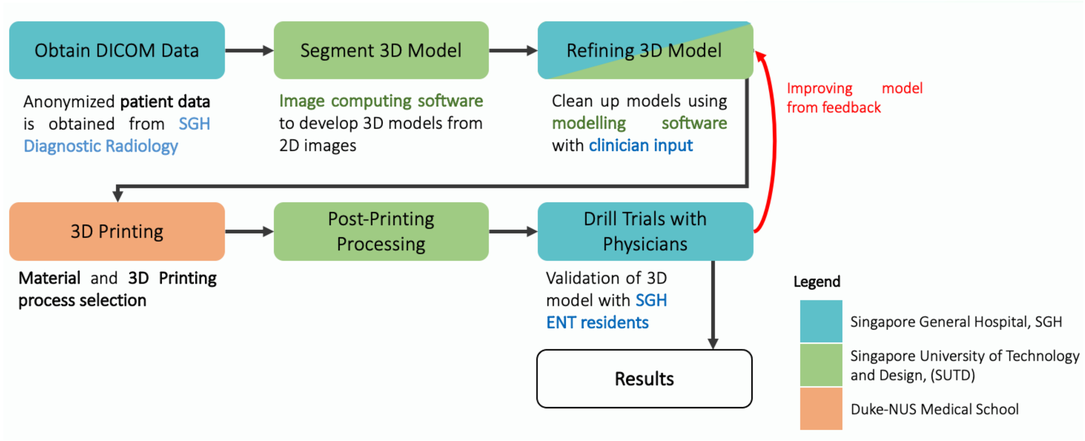
3D Printing holds much potential in complementing the practice of medicine due to its ability to faithfully reproduce high-fidelity, patient-specific or pathology-specific models in a relatively inexpensive fashion. Currently, some of the specialties of Medicine that employ 3D Printing are Cardiovascular Surgery, Neurosurgery and Musculoskeletal specialties (Rybicki & Grant, 2017). In this specialties, 3D Printing is used for patient education, surgical planning, surgical simulation and intraoperative guides. Further, developing 3D models is highly integrable with the practice of Medicine as they can be obtained through the Digital Imaging and Communications in Medicine (DICOM) dataset. This DICOM data can be obtained through common radiological modalities such as Computed Tomography (CT) scans and Magnetic Resonance Imaging (MRI) scans.

APPLICATION IN OTOLARYNGOLOGICAL SURGERY

For this project, the area of interest is in the practice of Otolaryngological Surgery, or more commonly known as Ear, Nose and Throat (ENT) surgery. The specific anatomical area of interest is the Temporal Bone (TB) which are the two major bones of the skull, or cranium. In ENT Surgery, TB models are relevant for the treatment of mastoid infection otosclerosis, and perforations of the tympanic membrane.

The current state-of-the-art for training ENT surgical residents is the usage of cadaveric TB models. There are many advantages of using cadaveric TB models such as providing similar haptic feedback and anatomical landmarks as real-life patients. However, some of the major disadvantages are that these cadaveric specimens are difficult to procure as they are expensive, limited in number, requires specialized laboratory facilities and have irregularities in their anatomy.

Therefore, the aim of this project is to develop a 3D printed high-fidelity, cost-effective, patient-specific Temporal Bone Model which can replicate anatomical features and haptic feedback of a cadaveric specimen.



This project is done with a unique collaboration between three institutions, namely, Singapore University of Technology and Design (SUTD), Singapore General Hospital (SGH) and Duke-NUS Medical School, which provide the specialized skills to fit the project needs.

The student researchers from SUTD provide the technical and engineering skills for designing and developing the 3D TB model. Medical consultants from SGH provide the clinical experience that guides the iteration of the models. Lastly, Duke-NUS provides the education and laboratory facilities for the fabrication of the TB models.

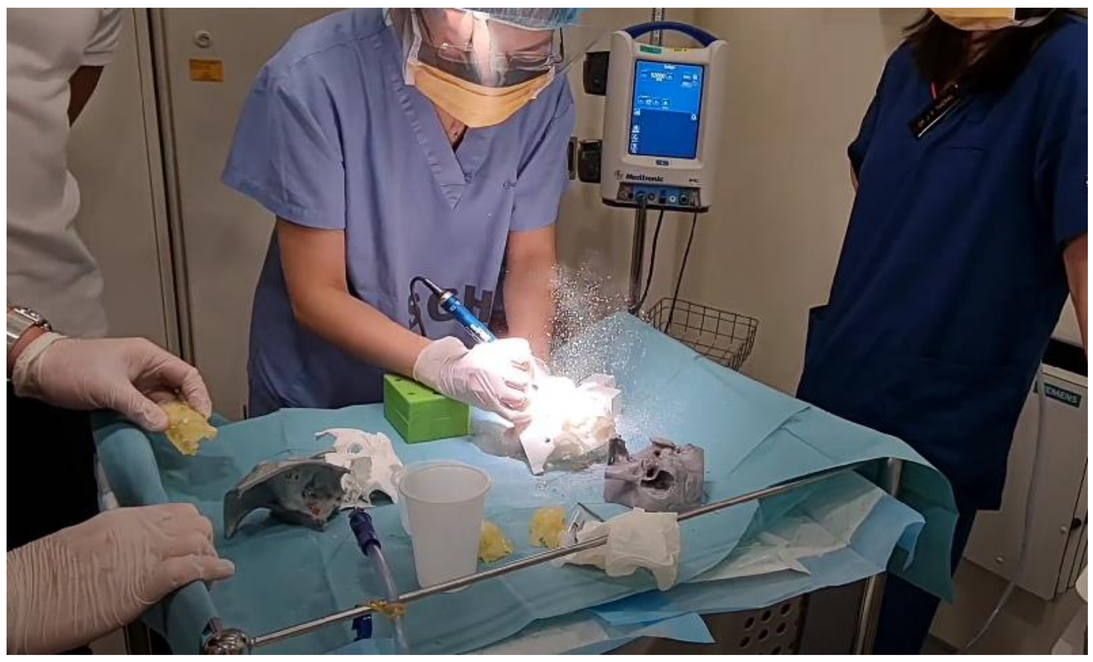
PROJECT OUTCOMES

There were multiple considerations for the 3D TB model developed. From the clinical perspective, the TB model had to possess certain key anatomical landmarks such as the mastoid air-cells, the ossicular chain and a through-hole cochlea for the model to be valuable for ENT surgeons. The 3D model should also accurately depict the haptic feedback of real TB under drilling. From the engineering perspective, the material choice of the model was significant as it could affect the sheer forces, resolution and affordability of the model.

Multiple rounds of iterations of the TB models was performed with consistent feedback from senior ENT residents on the model. This informed the choice of material of the model and the specific design parameters to be considered.

After a suitable model was developed, a large-scale clinical validation was performed with 13 ENT residents. Participants felt that the model was able to recreate major anatomical features well and produced haptic feedback like that of real TB. However, the model deviates from actual TB specimens in the areas of coloration, the absence of a tympanic membrane, and the definition of finer anatomical features.

Further work to refine the model is currently underway.



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Rybicki, F. J., & Grant, G. T. (2017). 3D printing in medicine. Cham: *Springer International Publishing.*

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