Prasannan A, Otolaryngol 2020, 10:4

Otolaryngology: Open Access

Short Communication Open Access

3D Printed Temporal Bones - Current Status and Future Directions

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Received date: May 02, 2020; **Accepted date:** July 07, 2020; **Published date:** July 14, 2020

Abstract

The well established 3D printing technology has today invaded into the field of biomedical science in a big way yielding fruitful results. The benefits from 3D printing have been noted in all specialities of modern medicine and its usefulness has been experienced successfully, right from developing virtual diagnostic measures, onto manufacturing biomedical appliances for treatment and recreating simulated body parts such as prosthetics and orthotics for restoring lost function. Further research is now underway to integrate this technology into stem cell science, so as to create in-vivo organs (i.e. bioprinting) to replicate lost tissues with identical appearance and function, provided the obstacles of tissue viability and immune compatibility are overcome. This exciting concept of 3D bioprinting prevails as the next frontier in medical science and is explored in this review with an example on its role in recreating temporal bones as simulated reality for Otology practice.

Keywords: 3D Printing; Bioprinting; Simulated reality; Temporal bone

Introduction

Medicine is an ever evolving field with no boundaries for ground-breaking research. In this era of advanced technology which creates virtual, simulated and augmented reality, cutting-edge 3D printing has now emerged in the forefront proving fruitful in numerous realms of clinical practice. 3D printing is a succeeding step to augmented reality (AR) where the later enhances the viewer's perception by overlaying computer generated virtual enhancement into real life, when virtual reality (VR) could only give computer generated simulation of real world [1, 2]. Integrating the third dimension into medical science is vital to understand the nuances of the human body and recreate its morphology and function in the most optimal way. This basic necessity led to the emergence of 3D printing and bioprinting, which has found applications in clinical practice [1, 2].

3D printing method uses materials like polylactic acid (PLA), acrylo-nitrile-butadiene-styrene (ANBS), hydroxyapetite etc. which have the consistency of natural bone and tissue, to compose physical objects from computer generated digital design. Augmented reality used in navigation based surgeries aiding in safer and less invasive procedures is now integrated with 3D printing technology and used in the field of surgical planning for better understanding of the disease/condition as well as for training purposes [3-6].

This has been successfully used in the field of cardiothoracic and neurosurgery which are complexed by congenital anomalies and anatomical variations. 3D printing has expanded onto other specialities and ENT is one field which has caught up in a big way. Presently, its applications in otorhinolaryngology cover the vast expanse of the subject including otology, laryngology/airway surgery, skullbase surgery, head and neck reconstruction and facial aesthetic/plastic surgery.

3D Printed Temporal Bones

Otology has been a challenging surgical subspecialty well known for its micro-anatomical complexities. Otological surgery is an art with the learning curve quite steep from the beginner to master level and it may take a surgeons life-time to achieve pure mastery based on years of experience. Otologists have always been fascinated with recreating the temporal bone - termed as 'the most beautiful and complex bone in the human body', in its 3 dimensional entirety akin to the natural bone. The advent of 3D printing has today brought into reality this possibility of manufacturing temporal bones which helps to understand the intricacies of the bone, its pathology and its relationships with vital structures better. Thereby, 3D printed temporal bones are in high demand both for practicing and training in Otological surgery [4, 5].

For 3D printing initially HRCT (High resolution computed tomography) images of the temporal bone is taken and these images are converted to DICOM (Digital imaging and communication in medicine) images, which are loaded onto a 3D printer. The specific regions of interest are defined without error using a 3D slicer and a series of 3D surface models are prepared which are then converted to STL (Standard tessellation language) format and finally 3D fabrication is done using the 3D printer. Such a precise and comprehensive modelling process recreates the temporal bone as a perfect match to the original bone which was scanned [1- 7].

These 3D printed bones help in surgical planning and patient counselling, mostly in revision cases with extensive pathology and also for implanting hearing devices especially in patients with anatomical variations and congenital deformities. Simulating surgery on 3D printed bone with navigational assistance helps Otologists to practice before encountering the real scenario. This provides confidence to plan the procedure well and overcome surgical challenges better, while reducing morbidity and operating time.

In the present day, procuring both wet and dry cadaveric temporal bones for training is becoming a tedious exercise in many parts of the world, due to medico-legal issues, prohibitive cost and the risk of biomedical hazard if mishandled. Thereby trainees are experiencing less exposure to hands-on micro-drilling and have become more dependent on virtual skill learning via computer assisted models and by observing surgery, wherein the third dimension of haptic feedback / hand skill is lost. To seek this they need to attend temporal bone courses which charge daunting fees. Premier courses provide useful training in a compact time-bound way, but they remain short-lived in the trainees' memory, necessitating further training under supervision to gain more confidence to perform independent live surgery. In such a scenario 3D temporal bone models have come into vogue as a popular alternative for hands-on training among residents [2- 5].

Pearls and Pitfalls in Otology practice

3D printed temporal bones have been found to be useful in various studies and many centres have now incorporated this method for patient counselling, comprehensive surgical planning and for training residents in Otology with 'hands-on' experience matched to cadaveric dissection [3-7]. The major advantage seems to be enhanced counselling for patients with a better understanding of their disease, rather than being explained with 2D images like CT or MRI. Such patients become more compliant and informed including the risks of surgery well explained, which leads to better doctor-patient relationship, especially in this era of medico-legal litigations [2-5].

Printed temporal bones do have a few limitations presently like limited availability and cost issues. Although these bones appear to match natural bones, the material used is not perfect with a small range of morphological errors in the contents of the bone and there is also a risk of mechanical and thermal deformation. Further cost-effective models with newer and better biomaterials are under experiment and these should be able to separate tissue densities and define contents in a natural way, providing a more realistic experience for clinical use [5, 6].

Many instances of operating surgeons misguided by a few millimeters of errors in 3D models, while identifying vital structures is known and the technology is still evolving today to become perfect. To learn the skills flawlessly and perform in the most optimal way, surgeons and trainees wish to have a virtual/augmented reality simulation set-up integrated into the printed bone for a better hands-on experience, akin to a live surgical scenario in real time [2-7].

Future of 3D Printing and Bioprinting

3D printing has made its mark in clinical medicine today proving successful in patient counselling, better surgical planning and for training programmes. This may become standard of care in the near future. Integration of 3D models into navigational systems, have helped surgeons to provide better disease clearance with less morbidity. Expanding from temporal bone printing, models are now being created for complex skull base reconstruction especially in cancer surgery. Moulding of autografts using 3D models is on the anvil. Classic examples include carving of costal cartilage for reconstruction of microtia ears, rhinoplasty and laryngo tracheal reconstruction, mandibular reconstruction with fibular graft in cancer surgery, etc.

The final horizon in 3D bioprinting is the integration of live tissues into the printed models, whereby it could be possible to shape the organ which is required to be replaced using pluripotent stem cells or harvested tissue culture. This will provide an artificial replacement of a body part perfectly similar to nature. Such a prospect seems exciting in the realm of regenerative medicine.

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