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Three-Dimensional Printed Prosthesis for Repair of Superior Canal Dehiscence

Elliott D. Kozin, MD*, Aaron K. Remenschneider, MD, MPH*, Song Cheng, BM BCh, Hideko Heidi Nakajima, MD, PhD, Daniel J. Lee, MD

Department of Otolaryngology, Harvard Medical School, Boston, MA

Department of Otolaryngology – Head and Neck Surgery, Massachusetts Eye and Ear Infirmary, Boston, MA

Abstract

Objective: Surgery for superior canal dehiscence (SCD) involving the arcuate eminence carries a risk of hearing loss and vestibulopathy. This may occur from inadequate repair or a mechanical insult to the membranous labyrinth. Repair of SCD using a customized, fixed-length prosthesis may address current operative limitations and improve outcomes. Herein, we aim to 3-dimensionally (3D) print customized prostheses to resurface or occlude bony SCD defects.

Study Design: Feasibility study using human temporal bone model of superior canal dehiscence

Setting: Temporal bone laboratory

Subjects and Methods: Defects were created along the arcuate eminence of the superior semicircular canals (SSC) in cadaveric human temporal bones. Detailed measurements of each dehiscence were made, including arc of the dehiscence and radius of the SSC. The angle of the curvature of the SSC was estimated based on geometry. Using modeling software (SketchUp) and a 3D printer (FormLabs), prostheses were manufactured based on SSC dimensions and used to repair the defects.

Results: Cone beam accurately measured the size of the defect. Modeling software and 3D printers were able to design and print prostheses at a resolution within the size constraints of the SSC. The prostheses firmly occupied the SSC defect, reflected in post-repair digital volume tomography. Bone wax was placed over the prosthesis to ensure stability of the repair.

Conclusion: This novel approach to SCD repair could have advantages over current techniques. Refinement of prosthesis design and materials will be important if this approach is translated into clinical use.

Corresponding Author: Aaron Remenschneider, MD, MPH, Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, MA 02114, Aaron.Remenschneider@meei.harvard.edu.

*Contributed equally

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Introduction

Superior canal dehiscence (SCD) is a bony defect of the superior semicircular canal (SSC) that, when associated with vestibular and auditory complaints, is referred to as SCD syndrome (SCDS).¹ Surgical intervention is reserved for patients with debilitating auditory and/or vestibular symptoms.² SCD repair falls into two general categories: 1) “resurfacing” and 2) “occluding”. Resurfacing is performed by placement of a bone chip, fascia, cartilage, or bone cement over the defect. Occluding techniques are performed by placement of bone wax, bone chips or fascia within the lumen to plug both limbs of the canal. Each operative approach has a unique set of technical challenges, potential complications, and expected outcomes.^{3,4} Variable results and complications are thought to be due to damage to the membranous labyrinth from pressure fluctuations during surgery and/or migration of graft material. Taken together, SCD surgery stands to benefit from refinement in technique.

Recent advances in 3-dimensional (3D) printing technology may allow for critical improvements in current approaches to SCD repair. 3D printing allows the creation of customizable microscopic structures, utilizing high-resolution nozzles and medical grade ‘inks’.^{5–7} Prosthetic printing with titanium and hydroxyapatite has become commonplace in orthopedic and dental procedures.^{8,9} 3D printing, however, has not been readily applied to otologic surgery.

We hypothesize that by using 3D printer, a personalized, fixed-length prosthesis may be manufactured to firmly resurface or occlude an arcuate eminence defect. This novel approach would address limitations of current technique by tailoring the repair to the patient’s anatomy. We aim to 1) preoperatively measure and design a personalized prosthesis for SCD repair and 2) 3D print the prosthesis to address the defect in cadaveric temporal bones.

Methods**Temporal Bone and Digital Volume Tomography:**

Chemically preserved cadaveric temporal bones were utilized. Arcuate eminence defects are most common in SCD¹⁰ and representative dehiscences were created along the middle fossa floor using a microdrill and diamond burr. The size of defect was made in accordance to previously measured dehiscences (2–6.8mm).¹¹ Temporal bones underwent imaging on a digital volume tomography (cone beam) scanner (3D Accuitomo 170; J. Morita Corporation, Japan).

Semicircular Canal Dehiscence Prosthesis Design:

DICOM images were imported into OsiriX imaging software. (Pixmeo, Switzerland). Measurements of the SSC including radius, length and curvature of the defect were made. Using modeling software (SketchUp, Trimble Navigation Limited, USA), digital prosthetics were designed to resurface or occlude the superior canal.

3D Printing and Testing:

Prosthetics were fabricated using commercially available 3D printers: Form 1+ from FormLabs (Massachusetts, USA) using a plastic-based resin or Formiga by Eos (Munich, Germany) using plastic or aluminum-based materials. Materials were chosen based on the need for high resolution printing and radiopaque qualities. Prosthetics were measured to ensure accuracy of intended dimensions. Specific prosthetics were used to repair the arcuate eminence defects in temporal bones and subsequently re-imaged.

Results

Dehiscences identified on cone beam were consistent with previous studies.¹¹ (Fig. 1) Modeling software readily permitted the creation of a virtual prosthesis at sub-millimeter scale. (Fig. 2) Basic resurfacing and occlusive designs were attempted. The resurfacing prosthetic was designed with “wings” to sit on the surface of the canal, with a small “anchor” sitting within the canal to secure the prosthesis without occluding the lumen. In contrast, the occlusive prosthetic was designed to sit within the lumen of the canal, plugging both limbs.

In the example case, under surgical microscopy, basic resurfacing and occlusive prostheses were readily placed into the SCD with adequate curvature. (Fig. 2) After prosthetic placement, bone wax was gently overlaid for stability. Upon removal of the prosthesis, no bone wax entered the canal lumen. (Supplemental Fig.) A post placement scan demonstrated the prosthesis within the canal. (Fig. 3)

Discussion

We demonstrate a novel method of SCD repair using a “dehiscence prosthesis” fabricated with a 3D printer. Post-placement imaging shows that a custom fabricated prosthesis readily fits defects for occluding or resurfacing approaches. Given the limitations of current techniques where there is uncertainty as to the volume of occlusive material in the canal and the extent of its spread/migration, the use of a prosthetic may theoretically improve post-operative SCD repair outcomes. With a prosthetic, the degree of repair is determined preoperatively and may limit complications related to over-occlusion, or migration of materials used to resurface or occlude the canal. Radiopaque non-absorbable material, such as polydimethylsiloxane (PDMS), may also address issues of post-operative visualization of the repair.

The ability of 3D printers to manufacture objects at high resolution opens the door to new solutions for current surgical problems. Freely available software and inexpensive printers have democratized the 3D printing space. Our study demonstrates that 3D design and

printing may be used to create various sizes and shapes, and even personalized prosthetics for the inner ear. Given the ability to incorporate medications, such as steroids, into biologic printing materials, further advancements can be easily envisioned.

The use of a SSC prosthetic as described is clearly experimental. Changes to prosthetic design and use of US Food and Drug Administration approved materials, including hydroxyapatite or silicone¹², may provide for further improvements and address safety considerations. Nevertheless, given the rapid nature of evolving 3D technology, we aim to provide evidence of the technical feasibility of this approach to the otolaryngology community.

Conclusion

A novel approach to SCD repair using a 3D printed prosthesis can theoretically reduce problems associated with current techniques. Refinement of prosthesis design and printing materials will be important before translation of this approach into clinical use.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

References

1. Minor LB, Solomon D, Zinreich JS, et al. Sound- and/or pressure-induced vertigo due to bone dehiscence of the superior semicircular canal. *Arch Otolaryngol Head Neck Surg* 1998;124:249–58. [PubMed: 9525507]
2. Jung D, Lookabaugh S, Owoc M, et al. Dizziness is More Prevalent than Autophony Among Patients Who Have Undergone Repair of Superior Canal Dehiscence. *Otology & Neurotology* 2014;36:126–32.
3. Shaia WT, Diaz RC. Evolution in surgical management of superior canal dehiscence syndrome. *Curr Opin Otolaryngol Head Neck Surg* 2013;21:497–502. [PubMed: 23989599]
4. Vlastarakos PV, Proikas K, Tavoulari E, et al. Efficacy assessment and complications of surgical management for superior semicircular canal dehiscence: a meta-analysis of published interventional studies. *Eur Arch Otorhinolaryngol* 2009;266:177–86. [PubMed: 18953551]
5. Mironov V, Boland T, Trusk T, et al. Organ printing: computer-aided jet-based 3D tissue engineering. *Trends in biotechnology* 2003;21:157–61. [PubMed: 12679063]
6. Gratson GM, Xu M, Lewis JA. Microperiodic structures: direct writing of three-dimensional webs. *Nature* 2004;428:386. [PubMed: 15042080]
7. Compton BG, Lewis JA. 3D-printing of lightweight cellular composites. *Advanced materials* 2014;26:5930–5. [PubMed: 24942232]
8. Leukers B, Gulkan H, Irsen S, et al. Hydroxyapatite scaffolds for bone tissue engineering made by 3D printing. *Journal of Materials Science: Materials in Medicine* 2005;16:1121–24. [PubMed: 16362210]
9. Tamimi F, Torres J, Al-Abedalla K, et al. Osseointegration of dental prosthesiss in 3D-printed synthetic onlay grafts customized according to bone metabolic activity in recipient site. *Biomaterials* 2014;35:5436–45. [PubMed: 24726538]
10. Lookabaugh S, Kelly H, Carter M, et al. Radiologic Classification of Superior Canal Dehiscence: Implications for Surgical Repair. *Otolaryngol Clin North Am* 2014.
11. Saliba I, Maniakas A, Benamira LZ, et al. Superior canal dehiscence syndrome: clinical manifestations and radiologic correlations. *Eur Arch Otorhinolaryngol* 2014;271:2905–14. [PubMed: 24162764]

12. Hahn Y, Zappia J. Modified resurfacing repair for superior semicircular canal dehiscence. *Otolaryngol Head Neck Surg* 2010;142:763–4. [PubMed: 20416470]

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Figure 1: Creation and measurements of superior canal dehiscence.

A: Bracket demonstrates dehiscence along the arcuate eminence. B. Pöschl view of dehiscence prior to prosthesis placement. Radius and arc length depicted. C-D. Cone beam scan following placement of prosthesis in Pöschl and Stenvers view. Arrow indicates radiopaque aluminum-based (Formiga) occlusive prosthesis in place.

Figure 2: SCD Prosthesis.

A. Basic occluding design. B. 3D printed occluding prosthesis. C. Basic resurfacing design (FormLabs). D. 3D printed resurfacing prosthesis. (FormLabs)

Figure 3: Placement of prostheses.

A-B: A: prosthesis adjacent to SCD opening (bracket). B: Occluding prosthesis placed directly within canal. C-D: Basic resurfacing design. C: Resurfacing prosthesis next to dehiscence (bracket). D: Prosthesis sits on surface of canal with edge barely in canal, securing prosthesis it into place.