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Temporal bone anatomy characteristics in superior semicircular canal dehiscence

Marrigje A. de Jong [a], David J. Carpenter [b], David M. Kaylie [b], Erin G. Piker [c], Dennis O. Frank-Ito [b,d,e,*]

[a] Department of Otorhinolaryngology/Head and Neck Surgery, Hadassah Hebrew University Hospital, Jerusalem, Israel
[b] Division of Head and Neck Surgery & Communication Sciences, Duke University Medical Center, Durham, NC, USA
[c] Department of Communication Sciences and Disorders, James Madison University, Harrisonburg, VA, USA
[d] Computational Biology & Bioinformatics, Duke University, Durham, NC, USA
[e] Department of Mechanical Engineering and Materials Science, Duke University, Durham, NC, USA

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Abstract

Introduction: Superior semicircular canal dehiscence (SCD) remains difficult to diagnose despite advances in high-resolution computed tomography (HRCT) imaging. We hypothesize possible associations between gross temporal bone anatomy and sub-millimeter pathology of the semicircular canals, which may supplement imaging and clinical suspicion. This pilot study investigates differences in gross temporal bone anatomic parameters between temporal bones with and without SCD.

Methods: Records were reviewed for 18 patients referred to an otology clinic complaining of dizziness with normal caloric stimulation results indicative of non-vestibular findings. Eleven patients had normal temporal bone anatomy while seven had SCD. Three-dimensional reconstruction of every patient's temporal bone anatomy was created from patient-specific computational tomography images. Surface area (SA), volume (V), and SA to V ratios (SA:V) were computed across temporal bone anatomical parameters.

Results: SCD temporal bones have significantly smaller V, and larger temporal bone SA. Mean (±SD) V was 21,484 ± 3,921 mm^3 in temporal bones without SCD and 16,343 ± 34,471 mm^3 for those with SCD. Their respective SA were 13,733 ± 1,603 mm^2 and 18,073 ± 3,002 mm^2. Temporal bone airspaces and lateral semicircular canals did not demonstrate significant differences where SCD was and was not present. Plots of MV_{warm} response against computed SCD temporal bone anatomic parameters (SA, V and SA:V) showed moderate to strong correlations: temporal bone SA:V ($r = 0.64$), temporal bone airspace V ($r = 0.60$), temporal bone airspace SA ($r = 0.55$), LSCC SA ($r = 0.51$), and LSCC-to-TM Distance ($r = 0.65$).

Conclusions: This analysis demonstrated that SCD is associated with decreased temporal bone volume and density. The defect in SCD does not appear to influence caloric responses.

Keywords: Temporal bone; Anatomy; Superior canal dehiscence; Superior semicircular canal dehiscence

1. Introduction

Superior semicircular canal dehiscence (SCD) involves discontinuity of the bone overlying the superior semicircular canal (SSCC), creating a third window in the inner ear. Normal pressure gradients for the endolymphatic flow are disturbed and patients typically present with auditory and

* Corresponding author. Division of Head and Neck Surgery & Communication Sciences, Department of Surgery, Box 3805, Duke University Medical Center, Durham, NC 27710, USA. Fax: +1 919 613 6524.
E-mail address: dennis.frank@duke.edu (D.O. Frank-Ito).

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vestibular symptoms such as hyperacousis, autophony, oscillopsia and vertigo induced by loud sound or pressure (Ho et al., 2017). High-resolution computed tomography (HRCT) is the preferred imaging modality for confirming SCD. However, false positive radiologic findings and asymptomatic radiographically apparent dehiscence limit the diagnostic utility of HRCT. These scans do not permit differentiation of bone thinner than 0.1 mm from true dehiscence. In normal subjects, bone overlying the SSCC has an average thickness of 0.67 mm and standard deviation of 0.38 mm, and the proportion of normal individuals with an overlying SC bone thickness <0.1 mm is greater than the incidence of SCD in the general population (0.05%) (Carey et al., 2000). Accordingly, the positive predictive value of HRCT for SCD is only 57% (Cloutier et al., 2008).

Given the diagnostic limitations of HCRT, SCD is confirmed in the clinical setting by additional physiologic tests including audiometry and calorimetry. Audiometric findings associated with SCD include air-bone gaps and negative bone conduction thresholds at lower frequencies (Ho et al., 2017) Caloric testing is commonly performed in patients with SCD due to associated complaints of vertigo. However, the utility of caloric testing as a diagnostic tool for SCD has been questioned because the SSCC is not reached by caloric stimulation (Ichijo, 2012). The relationship of temporal bone anatomy to caloric output has been described in previous reports of healthy subjects, and may represent an additional means of identifying subjects with SCD based on their temporal bone anatomy (Patki et al., 2016).

Pursuing additional SCD diagnostic strategies is warranted. We hypothesize that SCD may demonstrate unique anatomic characteristics at the level of the gross temporal bones that may assist clinicians in cases where HRCT findings are indeterminate at the SSCC. This hypothesis is based on previous characterizations of SCD anatomy that demonstrated a propensity for uniform SSCC bone thickness bilaterally in patients with and without SCD (Carey et al., 2000; Hirvonen et al., 2003; Gracia-Tello et al., 2013). However, the clinical applicability of these previous reports remains limited by HRCT resolution constraints in distinguishing between thin overlying SSCC bone (non-SCD) and true dehiscence (SCD). Three-dimensional volume reconstruction provides a novel method for comprehensive analysis of SCD temporal bone anatomy. We therefore provide an exploratory pilot study to characterize the temporal bone anatomic differences in patients with and without SCD.

2. Methods

This is a retrospective study approved by the Duke University Health System Institutional Review Board. Records were reviewed for 18 adult subjects from 2010 through 2015 presenting to the otology clinic with complaints of vertigo but normal caloric responses, 7 of these subjects (age: 37−67 years, median age is 57 years; gender: 2 males and 5 females) had SCD (per HCRT, audiometry, cervical vestibular evoked myogenic potentials [cVEMP], and clinical findings) and the other 11 subjects (age: 18−84 years, median age is 50 years; gender: 6 males and 5 females) had normal temporal bone anatomy. Of the 7 subjects with SCD 4 subjects had unilateral SCD and 3 subjects had bilateral cases of SCD, thus a total of 10 SCD temporal bones were identified. The methods used for vestibular testing are described elsewhere (Patki et al., 2016). No subjects had surgical or traumatic changes to the temporal bones.

Data collection − Temporal bone CT scans were obtained using a Siemens SOMATOM Definition Flash machine; with a section thickness of 0.6 mm, 512 × 512 matrix, rotation time of 1 s, and exposure time of 1825 ms. Digital imaging and communications in medicine (DICOM) images had 512 rows, 631 columns, and a pixel spacing of 0.176 by 0.176 mm. The scans were imported into and de-identified by Avizo 8.1 software (FEI Visualization Sciences Group, Burlington, MA). Computed anatomic parameters included surface area (SA) in mm^2, volume (V) in mm^3, and surface area-to-volume ratios (SA:V) in mm^{-1} for the following anatomic regions: temporal bone, temporal bone airspaces, and lateral semicircular canals (LSCCs). Temporal bone airspaces were defined as all continuous airspaces medial to the tympanic membrane (TM). The location of the TM was identified at the most lateral sagittal cut showing complete bony encasement of the auditory canal (Fig. 1). For anatomic regions were SA and V were computed, SA was defined as the area of all the surfaces covering that region; V is defined as the amount of space the anatomic region occupies. SA and V were calculated for each anatomic region using Avizo 8.1. To ensure consistency across all scans, the same co-author (M.A.dJ) manually performed all segmentations in the SCD cohort. The distance between the LSCC and TM was measured using ICEM-CFD™ 16.1 software (ANSYS, Canonsburg, PA). Fig. 1 shows the reconstruction of a temporal bone from a CT-scan showing unilateral dehiscence of the right SSCC.

Statistical analysis − Box-plots of computed anatomic parameters (SA, V and SA:V) for temporal bones with SCD from the 7 subjects were compared with normal temporal bones from the 11 subjects, and a two-tailed non-parametric Wilcoxon rank sum test analysis was used to investigate statistical significance at $\alpha = 0.05$. Monothermal warm caloric responses (MV_{warm}) were compared across the 22 unilateral ears from our cohort with normal temporal bones, 10 unilateral ears *affected* by dehisce from the SCD cohort, and 4 unilateral ears *not affected* by dehisce from the SCD cohort. Furthermore, MV_{warm} responses from the 10 unilateral temporal bones *affected* by SCD were plotted against their respective computed temporal bone anatomic parameters (SA, V and SA:V) and linear regression lines were fitted to determine associations between MV_{warm} and dehisced anatomic parameters.

3. Results

As indicated in Fig. 2, temporal bone volume (V) was significantly different between both cohorts ($p = 0.001$). Mean (±standard deviation) temporal bone V in temporal bones with SCD was 16,343 mm^3 ± 4471 mm^3 compared to

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