Received: 17 September 2022 | Revised: 15 October 2022 | Accepted: 19 October 2022

DOI: 10.1002/lio2.965

ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

Cochlear promontory anatomy relevant to development of subendosteal and transpromontory electrodes using 192-section ultra-high resolution temporal bone CT imaging

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Abstract

Objective: To characterize normative adult ranges for cochlear promontory thickness relevant to the development of subendosteal and transpromontory electrodes to rehabilitate various neurotologic disorders.

Patients: Adults (≥18 years).

Intervention: In vivo radiologic assessment using a 192-slice CT scanner (Force-192; Siemens Healthcare) with ultrahigh-resolution scan mode combined and iterative reconstruction.

Main Outcome Measure: Cochlear promontory thickness.

Results: Among 48 included patients (96 ears), the mean (SD) age was 56 (18) years (range 25–94) and included 25 (52%) women. Of that 12 patients (25%) had osteopenia ($n = 6$) or osteoporosis ($n = 6$). The mean (SD) body mass index was 28 (5) kg/m^2. The mean (SD) promontory thickness for the 96 temporal bones under study was 1.22 (0.24) mm (range 0.55–1.85). There was not a statistically significant association between age and promontory thickness (correlation coefficient .08; $p = .44$). Promontory thickness was significantly greater for men than women (mean 1.28 vs. 1.17 mm; $p = .03$) and increased with increasing body mass index (correlation coefficient .30; $p = .004$). Last, promontory thickness was significantly less for patients with osteopenia or osteoporosis compared with those without these conditions (mean 1.09 vs. 1.27 mm; $p = .002$).

Conclusions: Cochlear promontory thickness can vary by almost 1.5 mm across patients and is significantly associated with patient sex, body mass index, and comorbid osteopenia/osteoporosis. Subendosteal and transpromontory electrode placement techniques must account for this degree of variability.

Level of Evidence: IV

KEYWORDS

cochlear anatomy, cochlear implantation, cochleostomy, endosteal electrode, temporal bone imaging

1 | INTRODUCTION

Characterization of clinically relevant cochlear anatomy is necessary for expansion of surgical intervention options to rehabilitate neurotologic disorders. A growing emphasis has been placed in recent years on the potential use of subendosteal and transpromontory electrodes for rehabilitation of sensorineural hearing loss with cochlear implantation.[1–4] These implantation strategies may be particularly useful in scenarios where significant cochlear ossification precludes conventional intracochlear electrode placement; as a strategy to access apical regions of the cochlea with a separate electrode; or, as a means to atraumatically stimulate the cochlea without intracochlear electrode placement in patients with substantial residual hearing.[2] Similarly, investigation towards subendosteal electrode placement for the treatment of chronic tinnitus has received attention.[5] In light of the mounting interest in developing subendosteal and transpromontory electrode placement techniques to rehabilitate various neurotologic disorders, the current study was conceived with the primary intention of characterizing cochlear promontory thickness in adults using a 192-slice CT scanner with ultrahigh-resolution (UHR) scanning capability.

2 | METHODS

2.1 | Clinical data and imaging acquisition parameters

Following Institutional Review Board approval (IRB 16-007990), two reviewers independently evaluated 48 temporal bone CT studies ordered during the workup of various neurotologic conditions. Inclusion criteria for the current study required each patient to have no otologic disease or only be diagnosed with sensorineural hearing loss—patients had to be without evidence of other otologic disorders (e.g., chronic ear disease, otosclerosis), and the patient had to have had no prior history of ear surgery. Each imaging study was performed using a 192-slice CT scanner (Force-192; Siemens Healthcare) with UHR scan mode combined with iterative reconstruction. Images were then reconstructed using the highest possible resolution in axial, coronal, long axis (Stenver plane), and short axis (Pöschl plane) using routine clinical protocols employed at the investigators' institution. Measurements of promontory thickness, from outer periosteum to inner endosteum, were obtained using coronal acquisitions. In each case, the thinnest region of the cochlear promontory between the oval window and round window was measured perpendicular to the cochlear surface at the level of the malleus. Measurements from the two reviewers were averaged for analysis. For each patient, clinical data were also retrieved from the medical record. Osteopenia and osteoporosis were defined by dual-energy x-ray absorptiometry readings according to the World Health Organization criteria.[6]

Acquisition parameters for the 192-section CT scanner using the UHR mode (64 × 0.6 mm collimation) included a tube potential of 120 kV, 400 effective mAs, 1-s rotation time, and 0.5 helical pitch. The UHR mode uses an attenuating comb filter only along the fan angle direction, but not the cone direction. This improves dose efficiency and results in lower dose than that of the zUHR mode for the same level of image noise.[7,8] The automatic exposure control was off, and the volume CT dose index was 55.0 mGy. Both the z-axis and in-plane flying focal spot were used for data acquisition. Images were reconstructed using an iterative reconstruction algorithm (ADMIRE, Siemens Healthcare) with a special kernel designed for the UHR mode (U70). Images were reconstructed with 0.4 mm section thickness at 0.3 mm increments. The reconstruction field of view was 50 mm, and image matrix size of 512, resulting in pixel size of ~0.1 mm^2.

2.2 | Statistical methods

Continuous features were summarized with means and SDs and categorical features were summarized with frequencies and percentages. Promontory thickness was compared between the left and right ears using a paired *t*-test. Associations of patient features with promontory thickness were evaluated using Pearson correlation coefficients and two-sample *t*-tests. Statistical analyses were performed using SAS version 9.4 (SAS Institute; Cary, North Carolina). All tests were two-sided and *p* values < .05 were considered statistically significant.

3 | RESULTS

Among the 48 patients (96 ears) included in the study, the mean (SD) age of the cohort was 56 (18) years, ranging from 25 to 94 years, and included 25 (52%) women. Twelve patients (25%) had osteopenia

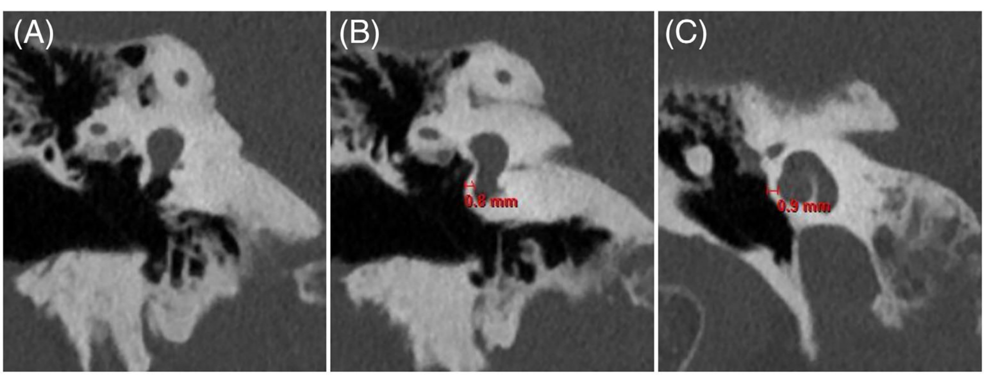

FIGURE 1 High-resolution thin-slice coronal images of the temporal bone acquired using 192-slice multidetector CT. (A) Region of cochlear promontory adjacent to the round window niche; (B) Measurement of cochlear promontory thickness in region between the oval and round windows; (C) Measurement of cochlear promontory thickness in region of cochlear apex

TABLE 1 Summary of associations of patient features with cochlear promontory thickness ($N = 96$)

Feature	Association*	p-value
Age at CT in years	0.08	.44
Sex		
Female	1.17 (0.23)	.03
Male	1.28 (0.25)	
Body mass index in kg/m^2	0.30	.004
Osteopenia or osteoporosis		
No	1.27 (0.23)	.002
Yes	1.09 (0.23)	

*Summarized with Pearson correlation coefficients or mean (SD) promontory thickness in mm.

($n = 6$) or osteoporosis ($n = 6$). The mean (SD) body mass index was 28 (5) kg/m^2. The mean (SD) promontory thickness for the left ear when averaged across reviewers was 1.20 (0.24) mm compared with 1.24 (0.25) mm for the right ear, for a mean difference (left minus right) of −0.04 (SD 0.15; 95% CI −0.08 to 0.00; $p = .06$).

When averaged across reviewers, the mean (SD) promontory thickness for the 96 temporal bones under study was 1.22 (0.24) mm, ranging from 0.55 to 1.85 (Figure 1). Associations of age, sex, body mass index, and presence of osteopenia or osteoporosis with promontory thickness among the 96 ears under study are summarized in Table 1. There was not a statistically significant association between age and promontory thickness (correlation coefficient .08; $p = .44$). Promontory thickness was significantly greater for men than women (mean 1.28 vs. 1.17 mm; $p = .03$) and increased with increasing body mass index (correlation coefficient .30; $p = .004$). Last, promontory thickness was significantly less for patients with osteopenia or osteoporosis compared with those without these conditions (mean 1.09 vs. 1.27; $p = .002$).

4 | DISCUSSION

Several investigations surrounding the expansion of existing electrode placement techniques for cochlear implantation have surfaced in recent years.[1–4] Successful implementation of subendosteal electrode placement requires understanding of normal anatomic ranges of cochlear promontory thickness as differing electrode designs and extent of surgical drilling may be required. A similar rationale can be applied to emerging data regarding transpromontory electrical stimulation of the cochlea for chronic disabling nonpulsatile tinnitus.[5]

Reporting normative data from nearly 100 adult temporal bones, this work demonstrates that cochlear promontory thickness exhibits a wide range across subjects, from 0.55 to 1.85 mm. Cochlear promontory thickness was statistically significantly greater among men and with increasing body mass index, paralleling existing literature surrounding bone mineral density in adults.[9–11] Interestingly, those with a clinical diagnosis of osteopenia or osteoporosis diagnosed by DEXA scan according to the World Health Organization criteria had significantly decreased cochlear promontory thickness.[6] Taken together, these findings help characterize cochlear promontory thickness with the most direct application surrounding the use of subendosteal and transpromontory electrode placement techniques. The utility and imaging parameters of UHR temporal bone CT imaging in the preoperative workup of patients undergoing nontraditional cochlear implantation techniques is also illustrated.

Limitations of this work extend from the single-center source of the data, using specific imaging protocols that may not be reproducible elsewhere. Necessary imaging parameters have been published previously, as well as included in the current report.[7,8]

5 | CONCLUSION

Cochlear promontory thickness can vary by almost 1.5 mm across patients and is significantly associated with patient sex, body mass index, and comorbid osteopenia/osteoporosis. Subendosteal and transpromontory electrode placement techniques must account for this degree of variability.

FUNDING INFORMATION

Internal departmental funding was used without commercial sponsorship or support.

CONFLICT OF INTEREST

Matthew L. Carlson reports holding pending patents 62/346,306, PCT/US2017/035617, and WO2017213978A1 on devices and methods for treating tinnitus with the use of electrical stimulation. No other authors have relevant conflicts of interest to disclose.

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How to cite this article: Marinelli JP, Patel NS, Lohse CM, Lane JI, Carlson ML. Cochlear promontory anatomy relevant to development of subendosteal and transpromontory electrodes using 192-section ultra-high resolution temporal bone CT imaging. *Laryngoscope Investigative Otolaryngology*. 2022;7(6):2084-2087. doi:10.1002/lio2.965