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Scalar Localization of the Electrode Array After Cochlear Implantation: A Cadaveric Validation Study Comparing 64-Slice Multidetector Computed Tomography With Microcomputed Tomography

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Hypothesis: Improved resolution available with 64-slice multidetector computed tomography (MDCT) could potentially be used clinically to localize the cochlear implant (CI) electrode array within the basal turn.
Background: In CI surgery, the electrode array should be inserted into and remain within the scala tympani to avoid injury to Reissner's membrane and the scala media. Correlating the position of the electrode in the basal turn with surgical technique and implant design could be helpful in improving outcomes.
Methods: After a standard left mastoid exposure of the round window niche through the facial recess performed on a cadaver head, an electrode array from a Nucleus Softip Contour CI was fully inserted through a cochleostomy. The head was then scanned axially on a 64-slice MDCT with 0.4-mm slice thickness and reconstructed into the oblique axial, oblique coronal, and oblique sagittal planes of the cochlea. The temporal bone was then harvested and imaged on a microcomputed tomographic scanner using 20-μm slice thickness. Identical reconstructions were made and compared with the 64-slice images to confirm exact location of the electrode array.
Results: The 64-slice MDCT accurately localized the electrode array to the scala tympani. This was best demonstrated in the oblique sagittal plane, identifying the electrode array in the posterior inferior portion of the basal turn, posterior to the spiral lamina.
Conclusion: This ex vivo validation study suggests that 64-slice MDCT has the potential to allow accurate localization of the CI electrode array within the basal turn of the cochlea. **Key Words:** Cochlear implant—Multi-detector CT—Temporal bone imaging—Microcomputed tomography—CT microscopy.
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Most patients with severe to profound bilateral sensorineural hearing loss can benefit from cochlear implantation (CI). The indications for CI are increasing to include treatment of selective high-frequency hearing loss in patients with functional low-frequency hearing. Surgical techniques in these patients require atraumatic insertion of the electrode array to preserve hearing and avoid damage to the scala media, the organ of Corti, and other delicate inner ear structures. Insertion into the scala tympani is the preferred route because the scalar lamina and basilar membrane provide the scala media a modest degree of protection. Scala vestibuli insertions are much more likely to cause traumatic disruption of Reissner's membrane and damage to the underlying hair cells, potentially leading to a loss of residual hearing. It was our intent in this study to determine if 64-slice multidetector computed tomography (MDCT) could be used to localize the electrode array within the scala tympani or scala vestibuli in an effort to provide the surgeon with information that could improve surgical technique and audiometric outcomes.

MATERIALS AND METHODS

A male cadaver head was obtained from the department of anatomy for the purposes of this study. A neurotologic surgeon (C.W.L.D.) preformed a standard left transmastoid exposure of the round window niche through the facial recess and made a 1-mm cochleostomy slightly anterior and inferior to the round window to avoid injury to the basilar membrane. The chorda tympani nerve was preserved. The endosteum of the scala tympani was carefully identified. The endosteum was penetrated with a 1-mm diamond burr at 5000 rpm. The Nucleus Softip Contour perimodiolar electrode array (Cochlear Corp., Ltd., Sydney, New South Wales, Australia) was then slowly introduced with standard advance off-stylet technique.

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CT examination of the postoperative cadaver head was performed on a 64-slice scanner (Sensation 64; Siemens, Forchheim, Germany) in the direct axial plane. Scanning was done in helical fashion using special "ultrahigh resolution plus" (UHR+) mode (120 kV; 320 mA s; pitch, 0.8; rotation time, 1 s). The UHR+ mode uses six central detector rows (0.6 mm each), an additional detector grid for super fine (0.35 mm) collimation, and the z-flying focal spot technology to achieve 0.25 mm of isotropic spatial resolution. The data set was reconstructed using a 70-mm field of view, 0.4-mm slice thickness, and 512 × 512 matrix yielding a voxel size of $0.14 \times 0.14 \times 0.4\ mm^3$.

After completion of the MDCT study, the temporal bone specimen was harvested from the male cadaver using the block technique as described by Schuknecht (1). Care was taken not to dislodge or disturb the electrode array, which was cut 1 cm from the cochleostomy site. The specimen had to be further reduced in size with an otologic drill to a maximal diameter of approximately 2.5 cm and length of 4 cm to fit properly in the micro-CT scanner. The specimen was scanned without decalcification or additional fixation. Micro-CT scanning differs from clinical scanning in that the object is rotated between the tube and camera that are stationary. The specimen sits on a rotating stage and turns 360 degrees about its vertical axis in 0.5-degree increments. At each angle, an x-ray exposure is recorded on the charge-coupled device camera. A single acquisition using a 20-μm slice thickness will cover approximately 2 cm of tissue. The specimen was scanned in two acquisitions, each taking 8 hours at 35 kV and 50 mA s. The two volume acquisitions were then combined using the Analyze 3-D voxel registration program as described by Hanson et al. (2) and Camp (3). The entire volume data set consisted of $20\text{-}\mu m^3$ voxels.

Images from both the micro-CT and 64-slice CT data sets were reconstructed in the oblique axial (in the plane of the basal turn parallel to the electrode array), oblique sagittal (in the plane of the long axis of the modiolus approximating the plane of Poschl), and oblique coronal (short axis of the cochlea approximating the plane of Stenver) planes. Multiplanar reconstructions and three-dimensional images were then evaluated to determine the location of the electrode array and the depth of electrode insertion.

Scalar localization was determined by the position of the array in reference to the scalar lamina; a position posterior to the scalar lamina localized the array to the scala tympani, and a position anterior to the scalar lamina localized the array to the scala vestibuli. Both micro-CT and MDCT images were reviewed side by side by two neuroradiologists (J.I.L. and R.J.W.).

RESULTS

The electrode array was localized to the to the scala tympani throughout its 360-degree insertion. The oblique sagittal plane of Poschl (Fig. 1) was the most useful plane of section for electrode localization because it best depicted the position of the spiral lamina within the basal turn. The oblique axial plane (Fig. 2) was useful for confirmation, but beam-hardening artifact on MDCT made it difficult to identify the scalar lamina. The oblique coronal plane (Fig. 3) was the least useful plane for localization but was preferred for estimating the depth of electrode insertion as were the three-dimensional images (Fig. 4).

DISCUSSION

CI for the treatment of severe to profound sensorineural hearing loss requires insertion of the electrode array into the basal turn of the cochlea. The scala tympani is the preferred chamber for insertion. Surgeons have recently been expanding the indications for CI to include patients with residual low-frequency hearing loss. The objective in these patients would be to provide electrical stimulation to the basal turn to achieve useful high-frequency hearing and amplify their residual low-frequency hearing with a hearing aid (4–6). It is critical in these patients that the surgery be as atraumatic as possible to prevent damage to the cochlear duct (scala media) within the basal and middle turns of the cochlea. The interscalar lamina and basilar membrane provide some degree of protection to the scala media when the

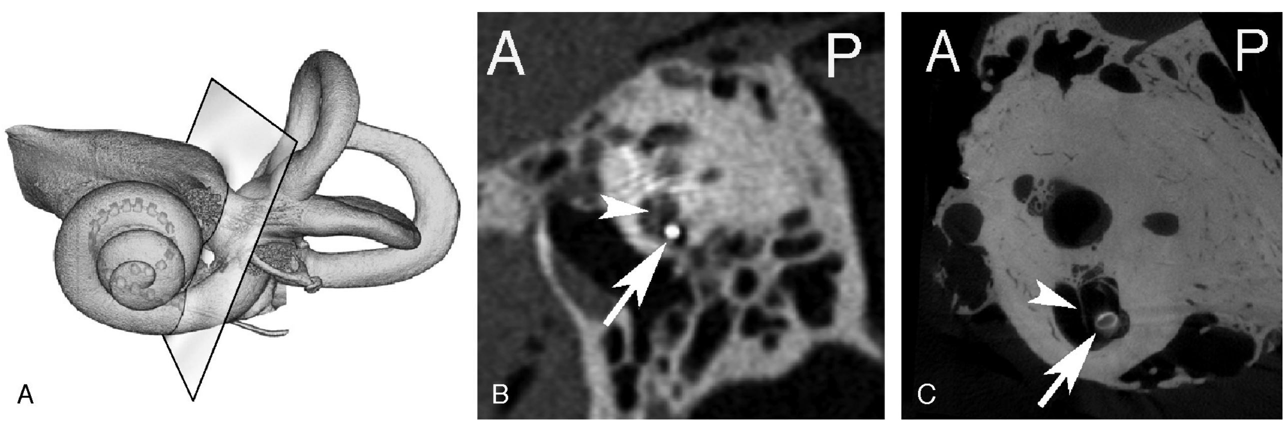

FIG. 1. Oblique sagittal reconstruction of electrode array in cadaver temporal bone. *A*, Three-dimensional reconstruction of micro-CT demonstrating oblique sagittal plane of section approximating the plane of Poschl. *B*, Sixty-four–slice MDCT reconstruction in the oblique sagittal plane demonstrating the position of the electrode array (arrow) posterior to the spiral lamina (arrowheads) localizing the array to the scala tympani. *C*, Oblique sagittal micro-CT confirming localization to the scala tympani. A, anterior; P, posterior.

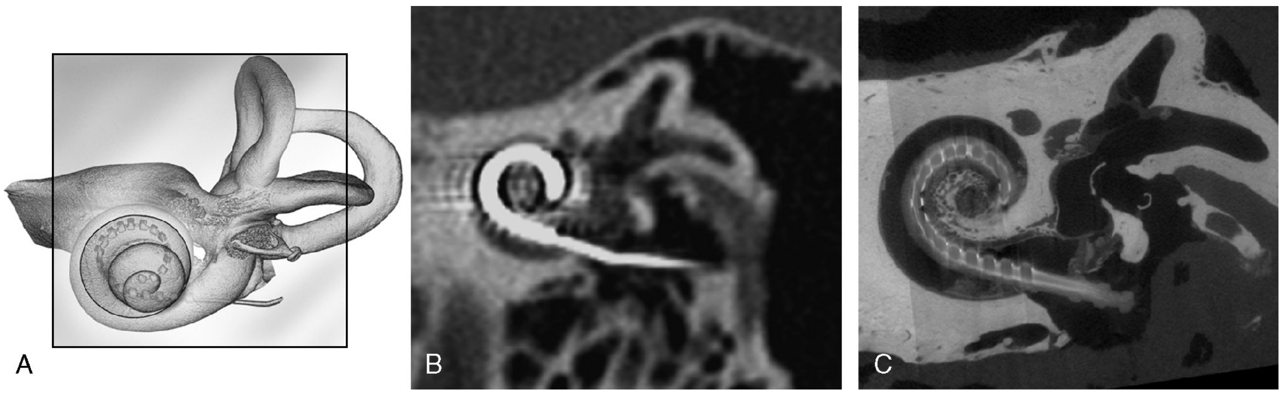

FIG. 2. Oblique coronal reconstruction of electrode array in cadaver temporal bone. *A*, Three-dimensional reconstruction of micro-CT demonstrating oblique coronal plane of section approximating the plane of Stenver. *B*, Sixty-four–slice MDCT reconstruction in the oblique coronal plane was ideal for assessment of the insertion depth of the electrode array. Scalar localization was not possible in this plane of reconstruction because it was in the plane of the spiral lamina. *C*, Oblique sagittal micro-CT confirming depth of insertion and perimodiolar positioning of array.

electrode array is inserted into the scala tympani (Fig. 1). Scala vestibuli insertions will more likely result in a disruption of Reissner's membrane with subsequent mixing of endolymph and perilymph, potentially resulting in loss of the residual hearing.

Traumatic insertion of the electrode array may result in injury to the stria vascularis, spiral ligament, and perhaps even the basilar membrane itself (7). There is considerable variation in the ability to see the round window niche and membrane through the facial recess approach. In an effort to preserve residual hearing, the cochleostomy is made anterior and inferior to the round window niche to ensure that the electrode array will enter posterior to the basilar membrane within the scala tympani (8,9). The endosteum of the scala tympani is carefully identified with a diamond burr. The endosteum can then be penetrated at low speed with a small diamond burr appropriate for the size of electrode being introduced or opened with a small hook. Suctioning of perilymph is strictly avoided. The electrode array is carefully oriented and slowly introduced to avoid creating potentially injurious hydrostatic forces. The cochleostomy site is sealed around the electrode with small pieces of fascia.

Previous histopathologic studies demonstrate that atraumatic surgical technique can significantly minimize cochlear trauma (7,10). Postnov et al. have demonstrated the utility of micro-CT in assessing the position of the electrode array within the cochlea in a cadaver specimen (11). This method of visualizing CI location is complementary to standard histopathology techniques and does not have the resolution to identify fine structural changes secondary to trauma, such as a fracture of the spiral lamina or injury to the spiral ligament. This is the first report to our knowledge correlating micro-CT to MDCT in temporal bone specimens. Correlation with

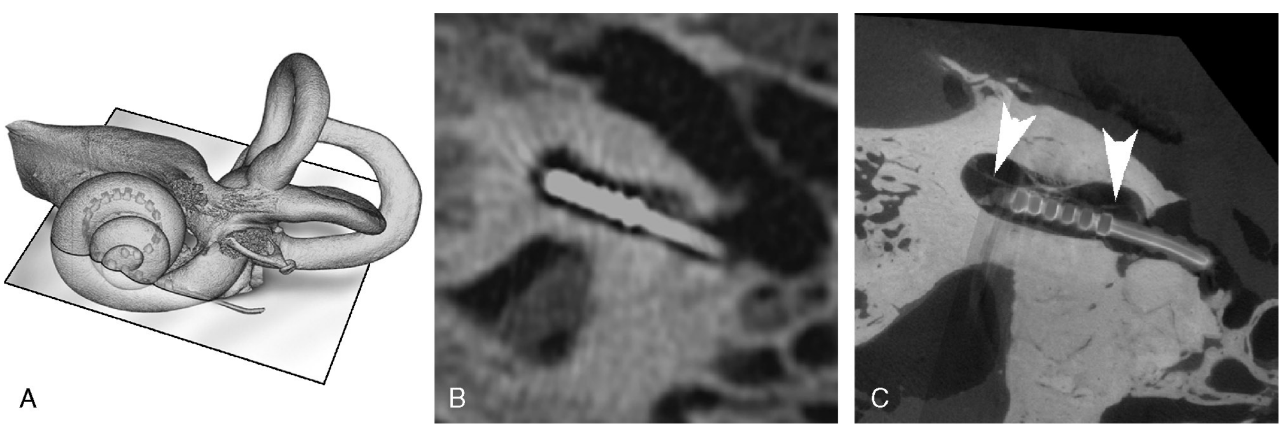

FIG. 3. Oblique axial reconstruction of electrode array in cadaver temporal bone. *A*, Three-dimensional reconstruction of micro-CT demonstrating oblique axial plane of section along the axis of the electrode array. *B*, Sixty-four–slice MDCT reconstruction in the oblique axial plane demonstrating the position of the electrode array approximating the posterior wall of the basal turn. Metal artifact obscures definition of the spiral lamina. *C*, Oblique axial micro-CT confirming localization of electrode array posterior to the scalar lamina (arrowheads) within the scala tympani.

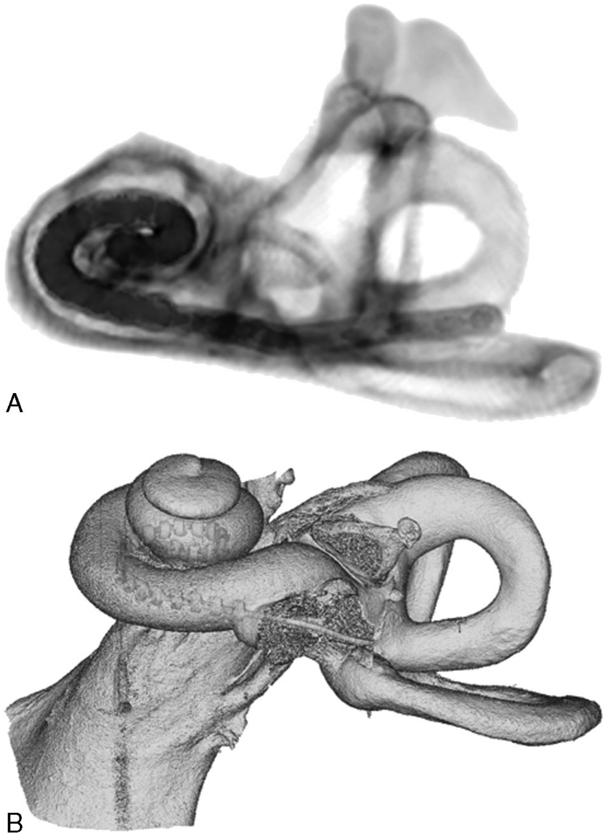

FIG. 4. Three-dimensional images of cadaver temporal bone from 64-slice MDCT (*A*) and micro-CT (*B*) demonstrating depth of insertion of the electrode array.

64-slice CT suggests that postoperative localization may be possible in the clinical setting. Our experience with multiplanar reconstructions from MDCT using 16-slice technology would indicate that the resolution in not adequate to permit array localization. The thinner collimation of 64-slice MDCT not only improves the resolution, but also facilitates metal artifact reduction by reducing the partial volume effect, which contributes to the inaccuracy of threshold-based metal detection algorithms (12).

Postoperative CT scanning of the temporal bones has been previously shown to provide clinically useful information in the setting of device failure secondary to electrode array migration, planning for revision surgery, postoperative perilymphatic leaks, and nonauditory stimulation (13–16). The results of our validation study would suggest that the resolution available with 64-slice MDCT using oblique sagittal and oblique axial reconstructions might allow accurate localization of the electrode array within the basal turn. The in vivo assessment of electrode array position may aid in refining surgical techniques to ensure proper scala tympani insertion and improve implant electrode design. Further studies evaluating a large number of postoperative patients with 64-slice CT will be needed to confirm the utility of these preliminary findings.

CONCLUSION

This study demonstrates that the location of the electrode array within the scala tympani can be confirmed using 64-slice MDCT in a cadaver model. This imaging technique warrants further study in a clinical cohort.

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