Radiologic Classification of Auditory Brainstem Implant Electrode Placement: Implications for Initial Device Activation

Samuel R. Barber M.S., Elliott D. Kozin, M.D., Mary E. Cunnane M.D., Sidharth V. Puram, M.D., Ph.D., Max Smith, M.D., Barbara S. Herrmann, Ph.D., Aaron K. Remenschneider, M.D., M.P.H., M. Christian Brown, Ph.D., Daniel J. Lee, M.D.

Department of Otology and Laryngology, Harvard Medical School, Boston, MA
Department of Otolaryngology – Head and Neck Surgery, Massachusetts Eye and Ear Infirmary, Boston, MA
Department of Radiology, Massachusetts Eye and Ear Infirmary, Boston, MA
Department of Audiology, Massachusetts Eye and Ear Infirmary, Boston, MA

ABSTRACT

Objective: To propose a classification system for resolving array position using Computed Tomography (CT) imaging. Study design: Retrospective case review Setting: Tertiary academic medical center Methods: Pediatric (n=4) and adult (n=6) ABI patients had true-axial reformatted CT scans. Classification Types I-V and A-C were assigned based on angle measurements using 3D maximum intensity projection (MIP) standard views. Audiometric data for active electrodes and side effects and programming data were collected. Results: Mean angles V, H, and T were 42.42° ± standard error of the mean (SEM) 8.9, 12.85° ± 10.30, and 37.3° ± 15.95. Mean distances D1 and D2 were 1.81 cm ± 0.10 and 1.05 cm ± 0.16 for adults and 1.37 cm ± 0.09 and 0.97 cm ± 0.08 for pediatric subjects. ABI arrays fell into 8 combinations of types, with differences observed for threshold values and the distribution of side effects. Conclusions: This study is the first to systematically analyze post-operative ABI array position. ABI placement varies widely and may support side-effect differences.

INTRODUCTION

• The auditory brainstem implant (ABI) provides auditory stimulus to patients who lack input from the cochlea or auditory nerve. Audiometric outcomes are highly variable within similar cohorts of patients in the number and distribution of active electrodes or side effects.1,2
• The surface ABI electrode array is blindly placed through the foramen of Luschka, and in close proximity to the dorsal cochlear nucleus of the brainstem1,3
• Intraoperatively evoked auditory brain responses (eABR) confirm placement without anatomic correlation. Computed tomography (CT) monitors for surgical complications postoperatively, yet no imaging modality characterizes array position.
• Herein, we aim to resolve ABI electrode array position using CT, as well as establish a classification system for electrode position along the brainstem.

METHODS

Patient Selection and Study Design
• Included ABI subjects had CT studies and audiometric data, with approval obtained from the Human Studies Committee (Protocols #340312, #441528).
• 3D Reconstruction of Post-operative CT
• True axial series were reformatted in Multplanar Reconstruction (MPR) using the McRae line. DICOM files were imported into Osirix MD v.7.0.1 64-bit.
• Basion and electrode tip coordinates were marked in MPR (Figure 1). 3D maximum intensity projection (MIP) revealed structures (Figure 2B).
• Linear measurements between marked coordinates were made in standard views – posterior (D1), lateral (D2), and superior (D3). Using ImageJ 1.47v, angles were – lateral (V), posterior (T), and superior (H) (Figure 3).

Classification System
• Types I-IV used angle V with respect to the horizontal (Type I: 71-90°; Type II: 21-70°; Type III: 0-20°; Type IV: 0-90° or lateral tilt in angle T).
• Types A-C were based on angle T with respect to the horizontal (Type A: 71-90°; Type B: 21-70°; Type C: 0-20°).
• Distances D1 and D2 were considered “tall” or “lateral” at twice the SEM.

Audiometric Data
• Post-activation data included the number and distribution of active electrodes, side effects, and psychophysical threshold (T) levels during perceptual testing.

RESULTS

Demographics
• 14 subjects (4 pediatric, 7 adult patients) were identified. Mean age at operation was 22 months and 43.4 years old, respectively.
• Of subjects, 9 out of 14 (64%) were male, and 11 out of 14 (79%) of ABIs were right sided.

Figure 1. Coordinates for the proximal electrode tip are marked using Multplanar Reconstruction in Osirix MD

Figure 2. 15 month old child with auditory nerve hypoplasia who underwent right retrosigmoid craniotomy and ABI placement (Cochlear Nucleus 24). 3D reconstructions allow for visualization of ABI electrode array position. (A) Conventional axial CT shows the array amidst windmill streak metallic artifact. (B) 3D MIP posterior view clearly shows electrode orientation. (C) 3D render using ABI CT data shows an artistic representation of a Type IB electrode over the dorsal cochlear nucleus, vertically upright and tilted medially.

Figure 3. Following reformating into a true axial series, screenshots were taken in Osirix MD from standard views and imported into ImageJ. In this standard lateral view, angle V with respect to the horizontal is measured. Points for angles are aligned with green coordinate markings made in MPR mode.

Figure 4. Classification types. Types I-III cover ranges of angle V (sagittal plane), where Type I is vertically upright and Type III is aimed posteriorly. Types A-C cover ranges of Angle T (coronal plane). Type A is vertically upright, whereas Type C is tilted medially. Type IV is reserved for any electrode with angle V outside 90° or lateral tilt in angle T.

Audiometric Data
• Audiometric data was available for 6 adult and 6 pediatric subjects.
• Mean threshold levels (Ts) for ABI programming were lowest for Type IA and II A (98.4 CL and 99.62 CL, respectively). Mean Ts were higher for Type IB and IIB, and highest for Type IV (135.29 CL, 142.36 CL, and 150.76 CL, respectively).
• Side effects were present in all Type IV (n=3) and Type B (n=2). Type IV arrays had the highest mean number of disabled electrodes (9.3). Type B arrays had a distribution of side effects in the distal and proximal tips.
• Subjects with outliers for D1 and D2 were analyzed. For "tall" arrays (D1), active electrodes were distributed more proximally. For "lateral" arrays (D2), active electrodes were either more distal or on one half of the array.

Figure 5. Side effects in subjects with Type IV, Type IB and Type IIB electrodes. (A) Side effects included facial tingling, which may correspond to the trigeminalthalamic tract. (B, C) Side effects included gagging in proximal electrodes and facial twitching in distal electrodes. Regions adjacent to the cochlear nucleus may correspond to the nucleus ambiguous in the rostral medulla and the facial colliculus in the pons.

DISCUSSION

• ABI electrode array position can be reliably observed and objectively measured using orthogonal views of standardized, reformatted images. 3D MIP takes advantage of higher pixel density values characteristic of bone mass and metal hardware.
• A classification system was devised a priori that characterizes electrode array position along the brainstem. Angles V and T together were sufficient to classify all arrays into Types I-IV and A-C. Although distances may be difficult to analyze without normalized data, interesting observations were noted.
• Placement is highly variable based on large ranges of values.
• Differences in thresholds and side effects were observed. It is not known exactly which structures the proximal or distal ends of arrays are stimulating. Future research in this area may determine preferable orientations.

• Intraoperative plain film lateral and posterior-anterior x-rays could provide similar imaging results to 3D MIP standard views. In this scenario, the use of imaging may be used alongside eABR intraoperatively to better optimize array placement and improve auditory outcomes (and reduce side effects from current spread).

■ Limitations
• Limitations of our study include the inability to eliminate all metal artifact in 3D reconstructions, the small chance for error during true axial reformating, and low sample size.

CONCLUSION

• This study is the first to analyze post-operative ABI array position.
• Arrays can be reliably observed and objectively measured using 3D reconstructions.
• ABI placement varies widely between patients and may correlate with range of outcomes seen among similar patient cohorts.
• Future prospective studies will include a larger number of patients to determine the predictive value of ABI location on audiologic outcomes and side effects.

ACKNOWLEDGEMENTS

We would like to thank the Helene and Grant Wilson Foundation for support of our ABI program.

REFERENCES


Correspondence: Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, 243 Charles St, Boston, MA 02114; daniel_llee@mei.harvard.edu