
ORIGINAL ARTICLE

Anatomic considerations for electrode implantation into the modiolus

Katya Assenova, MD; Stefan Stoyanov, MD, PhD; Todor Karchev, MD, DMSc

From the ENT Department,
Medical University of Sofia, Sofia
(K. Assenova, T. Karchev), ENT
Department, Medical Institute,
Ministry of Interior, Sofia (S.
Stoyanov), Bulgaria

Corresponding author:

Katya Assenova Slavkova, MD
ENT Department
University Hospital
"Tsaritsa Joanna"
26, Gen. Danail Nikolaev bld.
Sofia 1504, Bulgaria

Tel. : +359 887 593026
Fax : +359 2 9532018
E-mail : dr.assenova@gmail.com

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OBJECTIVE: The aim of this study was to assess the anatomic factors that enable successful direct implantation of an electrode into the modiolus.

METHODS: We studied the topographic location of the modiolus, including its apical part, to determine an appropriate surgical approach. Ten dissections of human temporal bones were performed. We measured the distance between the apex of the cochlea and the floor of the middle cranial fossa. The length of the modiolar axis was also measured. We used stereomicroscopy to study the modiolus for the possible placement of an electrode along its axis. Finally, via a cochleostomy on the anterior pyramidal surface, we introduced an experimental electrode from the apex to the base of the modiolus, aiming to determine the appropriate length for a modiolar electrode.

RESULTS: We found that the appropriate surgical approach to the modiolus is through middle cranial fossa. The cupola (apex) of the cochlea is located medial and anterior to the ganglion geniculi. The greater petrosal nerve served as a landmark. The cupola is about 2 mm below the upper surface of the petrous bone. An 8- to 10-mm electrode can be implanted without causing severe damage to the nerve trunk. The results of histologic studies revealed modiolar anatomic structures in detail.

CONCLUSIONS: The results of our study suggest that the implantation of an electrode into the modiolus is possible. Modiolar implantation could be an alternative to standard cochlear implantation, especially in patients with severe cochlear ossification and cochlear or middle ear malformation.

Spiral ganglion cells, which are in the cochlear modiolus, are widely considered to be neural elements that are stimulated by a cochlear implant (CI). Positioning a CI electrode adjacent to the modiolus (a spongy bone structure with multiple canals containing the axons of ganglion cells) may enable the delivery of more focused discrete fields of electrical stimulation, which in turn would reduce the current requirements and channel interaction that are associated with simultaneous stimulation. The scala tympani is so far the preferable site for electrode implantation, but the implanted electrode can cause erosion of the bone through the endosteum and may provoke an aseptic inflammatory reaction. However, long-term electrode implantation usually results in a relatively mild tissue response within the cochlea ⁽¹⁾.

Significant new bone formation, which frequently develops near a cochleostomy, is associated with trauma to the endosteum and/or the introduction of bone chips into the cochlea at the time of surgery. Electrode insertion trauma that involves the osseous spiral lamina or basilar membrane is more common in reimplanted cochleae. That type of damage is usually restricted to the lower basal turn and results in a more extensive ganglion cell loss ⁽²⁾.

CIs have numerous limitations. The success of cochlear implantation is questionable in patients who have either a malformation of the middle or internal ear or chronic otitis media and in those who have undergone radical mastoidectomy. Another major problem, cochlear ossification, is common in candidates for a CI. Cochlear ossification can occur as a consequence of meningitis, chronic otitis media, severe otosclerosis, autoimmune inner ear diseases (eg, Cogan's syndrome), temporal bone trauma, etc. The most common region in which cochlear ossification develops, regardless of its cause, is the basal turn ^(3,4), because subarachnoid inflammation reaches the cochlea through the cochlear aqueduct or internal auditory canal, and middle ear inflammation spreads across the round and oval windows (structures located in near the basal turn). Ossification at the round window and the proximal basal turn can complicate electrode placement.

The management of an ossified cochlea is a challenge for surgeons who perform cochlear implantation. In the last 2 decades, several techniques for cochlear implantation in ossified cochlea have been developed. Gantz and colleagues ⁽⁵⁾ described the total drill-out technique, which was modified by Balkany and colleagues as the intact canal wall drill-out procedure ⁽⁶⁾. Cohen and Waltzman ⁽⁷⁾ proposed the short inferior tunnel insertion, and Lenarz and colleagues ⁽⁸⁾ suggested the double-electrode array.

Cochlear implantation using various technical adaptations of electrode arrays and surgical procedures has been performed in partially and totally ossified cochleae. However, the functional results of such procedures are poor, perhaps because of the poor contact between electrodes and nerve endings or as a result of peripheral nerve degeneration, which is associated with ossification, in the cochlea.

The interface between the electrode and the cochlear nerve is a key area in which improvements in cochlear implantation might be effected. A notable decrease in stimulation threshold currents and power consumption could be achieved by an electrode that has been implanted directly into the cochlear nerve.

The use of a penetrating electrode is not a new idea. Simmons and colleagues ⁽⁹⁾ described cochlear nerve implantation performed with 6 stainless steel electrodes that had been wound around each other and were insulated at the tips. Hillman and colleagues ⁽¹⁰⁾ developed an array of silicon-based electrode needles (the Utah Slanted Electrode Array). That array, which has a 3-dimensional penetrating electrode architecture, achieves more focal stimulation than does a scalar array and, as a result, enables greater frequency selectivity.

Colletti and colleagues ^(11,12) were among the first investigators to use the middle cranial fossa approach for cochlear implantation with good results. In that technique, the electrode is introduced into the basal turn of the cochlea. One of the advantages of that method is that middle ear is bypassed and the risk of infection is lowered.

MATERIALS AND METHODS

To bypass the tympanic cavity (in patients with an infection) or an ossified or aberrant cochlear duct (in those with a cochlear anomaly or ossification), we decided to study the result of the direct implantation of an electrode into the modiolus. Our experiment was performed on 10 formalinized temporal bones from human cadavers. With adequate exposure of the middle cranial fossa floor and after identification of the greater superficial petrous nerve and the internal auditory canal, drilling was begun at the bony angle between the labyrinthine portion of the facial nerve and the greater superficial petrous nerve. After a cochleostomy had been performed, the top of the modiolus, which was surrounded by the apical cochlear coil, was visualized (Figure 1). A thin probe was inserted through the central portion of the modiolus from top to bottom (Figure 2). A plastic electrode was then introduced into the canal created by the probe (Figure 3). A thorough histologic analysis of the modioli was also performed.

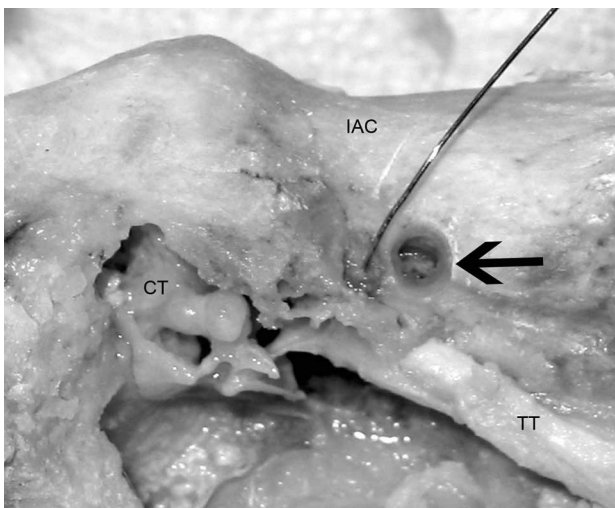


Figure-1: The probe shows the ganglion geniculi. The greater petrosal nerve has been resected. Note the cochleostomy (arrow), which is medial and anterior to the ganglion geniculi. IAC, Internal auditory canal; CT, cavum tympani; TT, tensor tympani.

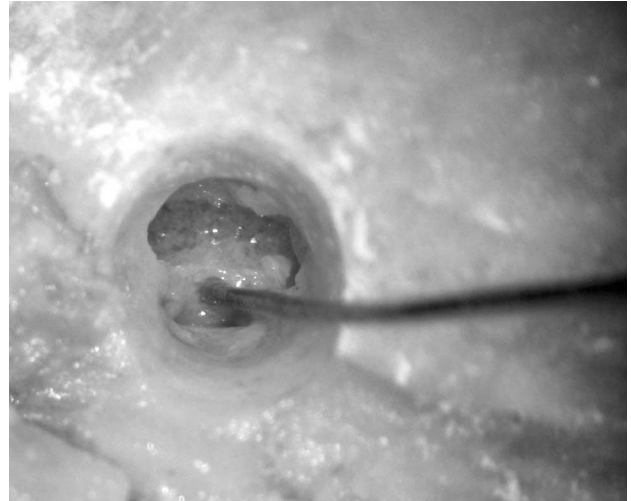


Figure-2: The probe is inserted from the top to the bottom of the modiolus. The apical cochlear coil is also visible.



Figure-3: An electrode inserted along the central modiolar axis. Note the correlation of the electrode with the cochlea. Bar length, 1 mm.

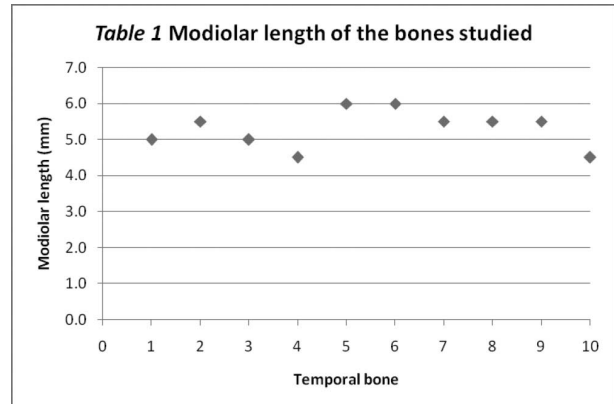
RESULTS AND DISCUSSION

It is well known that the anterosuperior part of the cochlea is in contact with the anterior petrous wall. The superior edge of the cupola cochleae is about 2 mm under and just medial and anterior to the ganglion geniculi. The surgical landmarks used in our study were the arcuate eminence, the internal auditory canal, and

(especially) the greater superficial petrosal nerve. The disclosure of the cupola cochleae sometimes requires petrous nerve resection.

During the surgical approach from the squamous temporal bone, the roof of the petrous bone is followed medially, and encountered in turn are the roof of the tegmen, the irregular projections of the arcuate eminence and the geniculate area, and finally the flattened meatal area, which is easily identifiable by its plateau-like appearance. The dura mater of the middle cranial fossa can be easily elevated until the meatal area is reached. There the dura becomes closely adherent to the internal meatal ridge. It is also fixed posteriorly along the superior border of the petrous bone where the superior petrosal sinus runs, as well as anteromedially over the region of the Gasserian ganglion and the carotid canal. The first part of the basal turn, which is beneath the vestibule and the internal auditory meatus, continues forward near the anterior wall of the meatus. The upper surface of the cupola cochleae is adjacent to the anterior cortex of the petrous bone. The cupola is located medial to the geniculate ganglion and just posterior to the hiatus of the petrosal nerves. At that point during cochleostomy, it is very unusual to encounter air cells. Particular care must be taken not to injure the ganglion geniculi, which is very close to the cochleostomy and is usually covered by just a thin sheet of acellular dense bone. The geniculate ganglion is often partially dehiscent, and in some patients, the bony canal between the ganglion and the point of emergence of the petrosal nerves may be 2 or 3 mm long. The Table shows the lengths along the modiolar axis of the 10 temporal bones.

The calculated average length of the modiolus is 5.3 mm (SD = 0.537). The modiolar nerve fibers join to form the cochlear nerve 2 to 3 mm after leaving the tractus spiralis foraminosus (Figure 4, 5). Thus an electrode with a length of about 8 to 10 mm can be implanted without causing severe damage to the nerve



trunk. Electrodes with those dimensions are available; for example the Nucleus Hybrid 10-mm electrode with 6 half-banded electrodes ("Cochlear" - 14 Mars Road, PO Box 629, Lane Cove NSW 2066, Australia) and the MED-EL Compressed Electrode Array with 12 pairs of electrode contacts that are equally spaced over a length of 12.1 mm ("MED-EL" - Fürstenweg 77a, A-6020 Innsbruck, Austria).



Figure-4: A longitudinal section through the cochlea and internal auditory meatus is performed. The basal, middle, and apical turns of the cochlea are shown. The separate nerve fibers join to form the auditory nerve trunk about 2 mm after emerging from the tractus spiralis foraminosus.

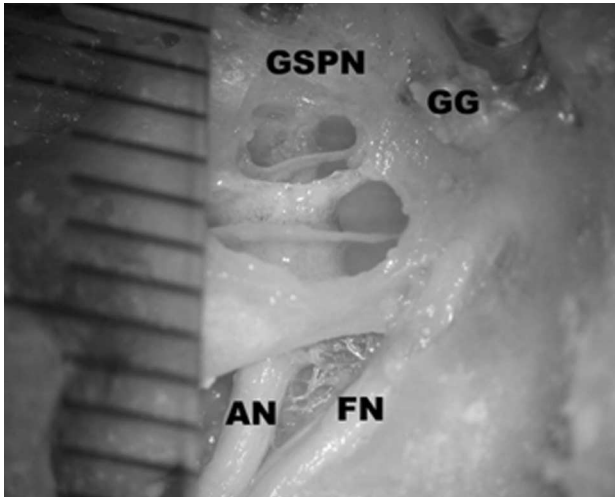


Figure-5: A longitudinal section through the cochlea. Distance between marks, 1 mm. GPN, Greater petrosal nerve; GG, ganglion geniculi; AN, auditory nerve; FN, facial nerve.

The electrode-neural interface is very important for signal transduction. Scalar electrode arrays are limited in the specificity of neural stimulation because of the comparatively low number of effective channels that can provide information. If a safe and reliable intraneural electrode system could be developed, improvement in stimulation specificity would be possible.

Our stereomicroscopic examination of longitudinal sections of the modiolus revealed the spiral ganglion cells and their axons (Figure 6), which course downward spirally and form the cochlear nerve. During stereomicroscopic dissection, the cochlear nerve was identified at the base of the cochlea (Figure 4) and some nerve fibers were followed along the modiolus from the basal coil to the apex. The central processes of the neurons of the spiral ganglion pass through the spiral canals, emerge from the cochlear coil, and fuse into a single longitudinal canal to form the cochlear nerve.

The modioli obtained from human cadavers were also examined with light microscopy, which, in the serial sections perpendicular to the axis of each modiolus, clearly showed the longitudinal canals and

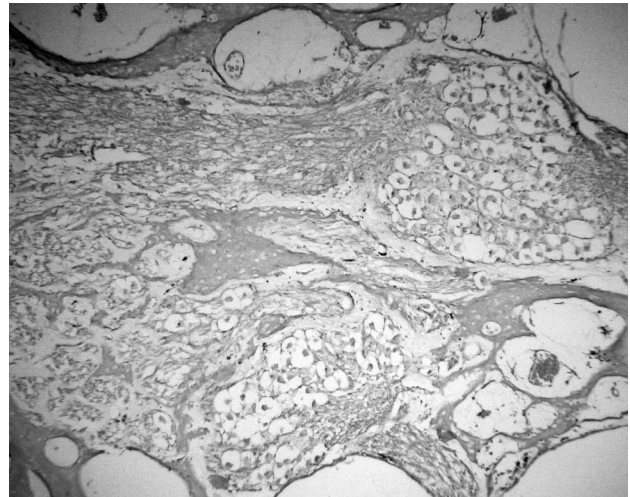


Figure-6: A transverse section through the modiolus and basal cochlear turn (hematoxylin-eosin, original magnification x20).

the initial portion of the cochlear nerve. The spongy bony structure of the modiolus surrounded the nerve fibers. Transverse sections showed many small oblique canals (Figures 6 and 7). The auditory neurons, which are in Rosenthal's canal, wind around the modiolus (Figure 8). Our observations confirmed the finding of Spoendlin⁽¹³⁾, that the density of auditory neurons is highest in the upper basal and lower middle coils. Sacrificing the nerve fibers and neurons at the apical part of the modiolus probably will not seriously compromise voice perception.

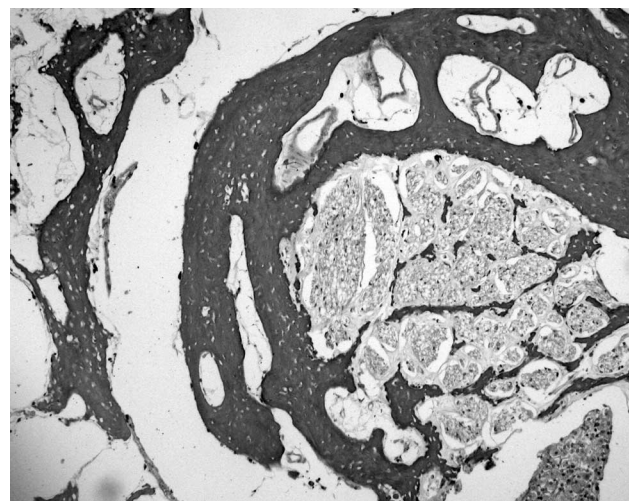


Figure-7: A transverse section through the modiolus (hematoxylin-eosin, original magnification x40).

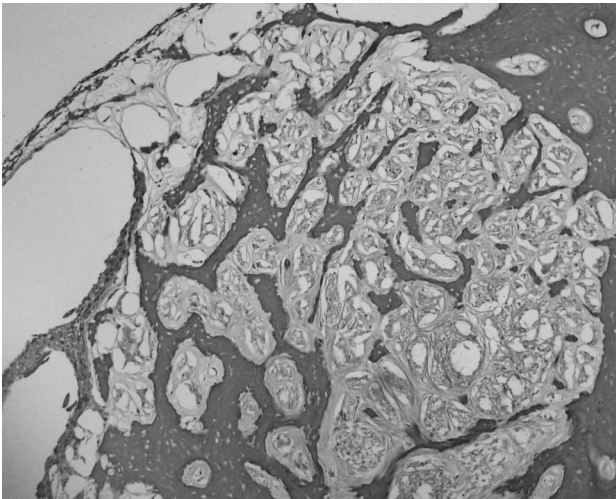


Figure-8: A peripheral section through the modiolus reveals numerous spiral ganglion cell bodies (hematoxylin-eosin, original magnification x30).

Arterial blood supply to the cochlea is maintained by an artery that spirals around the modiolus. Arterioles leave the artery, run centrifugally, and radiate (ramifying several times) over the scala vestibuli and the spiral lamina. The spiral capillary systems in the external wall and in the spiral lamina are drained by centripetally radiating collecting venules that empty into 1 or 2 veins running spirally around the modiolus ⁽¹⁴⁾. This supports our observation that in the central part of the modiolus there are no blood vessels that could bleed significantly during implantation (Figure 9).

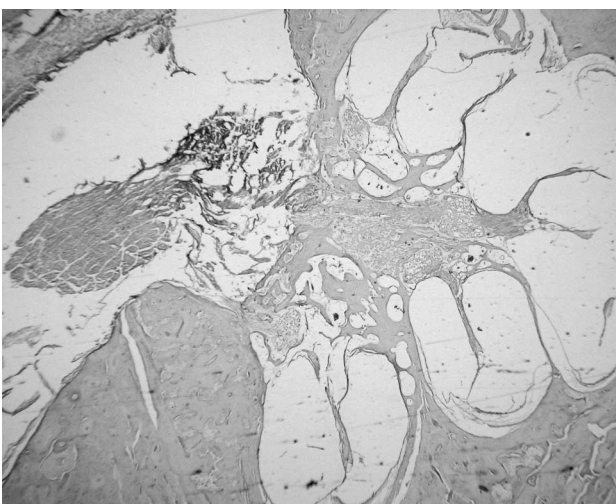


Figure-9: Note the absence of blood vessels along the modiolar axis (hematoxylin-eosin, original magnification x12).

The structure of petrous bone allows the relatively uneventful opening of the cochlea through the middle cranial fossa. The superior edge of the cupola cochleae is under, medial, and anterior to the ganglion geniculi. The arcuate eminence, the internal auditory canal, and (especially) the greater superficial petrosal nerve can serve as reliable surgical landmarks. A relatively broader cochleostomy facilitates the visualization of the modiolar apex, which is surrounded by the apical cochlear turn. An electrode with a length of about 8 to 10 mm could be introduced into the modiolus without injury to important modiolar structures. In our opinion, the electrode design should reflect the tonotopic organization of the cochlea by releasing higher frequencies at the basal part of the modiolus and lower frequencies in the apical part.

In summary, we suggest that the implantation of an electrode in the modiolus can be an alternative to standard cochlear implantation mainly in patients with severe cochlear ossification.

REFERENCES

1. Clark G. Cochlear implants: fundamentals and applications. New York: Springer-Verlag, Inc; 2003.
2. Shepherd RK, Clark GM, Black RC. Chronic electrical stimulation of the auditory nerve in cats. Physiological and histopathological results. *Acta Otolaryngol Suppl* 1983;399:19-31.
3. Paparella MM, Sugiura S. The pathology of suppurative labyrinthitis. *Ann Otol Rhinol Laryngol* 1967;76:554-86.
4. Green JD Jr, Marion MS, Hinojosa R. Labyrinthitis ossificans: histopathologic consideration for cochlear implantation. *Otolaryngol Head Neck Surg* 1991;104:320-6.
5. Gantz BJ, McCabe BF, Tyler RS. Use of multichannel cochlear implants in obstructed and obliterated cochleas. *Otolaryngol Head Neck Surg* 1988;98:72-81.

6. Balkany T, Luntz M, Telischi FF, Hodges AV. Intact canal wall drill-out procedure for implantation of the totally ossified cochlea. *Am J Otol* 1997;18:S58-9.
7. Cohen NL, Waltzman SB. Partial insertion of the nucleus multichannel cochlear implant: technique and results. *Am J Otol* 1993;14:357-61.
8. Lenarz T, Lesinski-Schiedat A, Weber BP, Issing PR, Frohne C, Buchner A, et al. The nucleus double array cochlear implant: a new concept for the obliterated cochlea. *Otol Neurotol* 2001;22:24-32.
9. Simmons FB, Epley JM, Lummis RC, Guttman N, Frishkopf LS, Harmon LD, et al. Auditory nerve: electrical stimulation in man. *Science* 1965;148:104-6.
10. Hillman T, Badi AN, Normann RA, Kertesz T, Shelton C. Cochlear nerve stimulation with a 3-dimensional penetrating electrode array. *Otol Neurotol* 2003;24:764-8.
11. Colletti V, Fiorino FG, Carner M, Pacini L. Basal turn cochleostomy via the middle fossa route for cochlear implant insertion. *Am J Otol* 1998;19:778-84.
12. Colletti V, Fiorino FG. New window for cochlear implant insertion. *Acta Otolaryngol* 1999;119:214-8.
13. Spoendlin H. Innervation densities of the cochlea. *Acta Otolaryngol* 1972;73:235-48.
14. Axelsson A. The vascular anatomy of the cochlea in the guinea pig and in man. *Acta Otolaryngol* 1968; suppl 243:3+.