Perimodiolar Electrodes in Cochlear Implant Surgery

WOLFGANG KARL GSTOETTNER[1], OLIVER ADUNKA[1], PETER FRANZ[2], JAFAR HAMZAVI[2], HANNS PLENK JR.[3], MARTIN SUSANI[4], WOLF BAUMGARTNER[2] and JAN KIEFER[1]

From the Departments of Otolaryngology, [1]JW Goethe University Frankfurt/Main, Frankfurt/Main, Germany, and [2]University of Vienna, Vienna, Austria, and the Departments of [3]Bone and Biomaterial Research, Histological-Embryological Institute, and [4]Pathology, University of Vienna, Vienna, Austria

Gstoettner WK, Adunka O, Franz P, Hamzavi J, Susani M, Plenk Jr. H, Baumgartner W, Kiefer J. *Perimodiolar electrodes in cochlear implant surgery*. Acta Otolaryngol 2001; 121: 216–219.

Perimodiolar-positioned cochlear implant electrodes have been developed in order to bring the electrode contacts as close as possible to the spiral ganglion cells, which are the target of electrostimulation. This results in lower electrical thresholds, higher dynamic ranges and less channel interaction when compared with normal implant electrodes which are usually located peripherally within the scala tympani. In this study we evaluated 4 different types of perimodiolar electrode: the Clarion Preformed electrode, the Clarion Preformed electrode with positioner, the Nucleus Contour electrode and the Med-El Perimodiolar Combi 40 electrode. These devices require different approaches to achieve a perimodiolar electrode position. The electrodes were inserted in fresh human temporal bones. After processing these bones with the electrodes *in situ* by employing a sawing, grinding and polishing technique, the inner ear structures as well as the electrode positions could be evaluated in detail. All electrode types studied had a more or less perimodiolar position; however, each type produced a certain amount of trauma to cochlear structures which is discussed in relation to mechanical properties. Further human temporal bone studies with improved perimodiolar cochlear implant electrodes are necessary in order to find an optimized type of electrode. *Key words*: *electrostimulation*, *hearing nerve*, *human temporal bones*, *neurostimulation*.

INTRODUCTION

Great progress has been made in recent years in the development and improvement of cochlear implants. Multichannel systems have become standard and speech perception scores have increased. Insertion into the tympanic scale of the cochlea generates physiological stimulation of corresponding hearing nerve fibers. Although many advances have already been made, there are still several issues to discuss with regard to cochlear implant surgery, one of which is insertion depth. We have shown that insertion depths of up to 30 mm are possible with limited trauma to cochlear structures (1, 2). Deep insertion positions the electrode contacts to more apical structures in the cochlea and thus stimulates lower frequencies. However, with these deep insertions the electrodes were found to be located peripherally within the scala tympani (3). Another relevant issue is the insertion trauma caused to the basilar laminar membrane and other cochlear structures. This could have a large impact because future cochlear implant models may deal with hair cell regeneration.

One new attempt at an improvement is to position the active electrodes close to the inner wall of the cochlea. The auditory neurons stimulated by a cochlear implant are represented as the spiral ganglion cells in the Rosenthal channel. These nerve structures are located at the fulcrum point of the cochlea. The human organ of Corti measures ≈ 32 mm and comprises 2.25–2.75 turns. The insertion length for an electrode positioned close to the modiolus would be ≈ 20 mm. Positioning the electrodes close to the inner wall of the cochlea would also lead to better-localized neural stimulation because the voltage could then be decreased. This might result in better speech perception.

A number of teams across the world are currently designing a cochlear implant electrode which hugs the modiolus. Modeling and animal experiments indicate that an electrode array positioned against the inner wall of the scala tympani produces lower thresholds, a higher dynamic range and reduced channel interaction. When inserting a free-fitting cochlear implant electrode the position attained is at the outer wall of the tympanic scale—far from the corresponding nerve fibers located in the modiolus. Manufacturers of cochlear implants have developed different approaches for bringing their electrodes close to the modiolus when inserted into the scala tympani. The aim of this study was to compare these new electrodes in terms of the resulting trauma to cochlear structures.

MATERIALS AND METHODS

At present, several different types of perimodiolar cochlear implant electrode are available:

The Preformed Clarion electrode and the Highfocus electrode with positioner are both manufactured by Advanced Bionics. Both arrays are designed for perimodiolar positioning inside the cochlea but use different approaches. The Clarion Preformed electrode is preshaped and an insertion tool is used to straighten the electrode prior to insertion. After being released from this tool the electrode should then curl towards the modiolus when inserted into the scala tympani. The Highfocus electrode is a free-fitting device which is located towards the inner wall by means of additional insertion of the positioner. Both electrodes feature 16 electrode contacts equally spaced in a row. The contacts are isolated by dielectric partitions and mounted perpendicular to the modiolus of the cochlea. As mentioned previously, a positioner ensures that all electrode contacts are located near the modiolus.

The newest device from Med-El is the Perimodiolar Combi 40 Electrode (PME C40). This is an adapted Combi 40 electrode system which consists of 12 active contacts equally spaced in a row. The electrode has a groove with a microscopic nitinol wire inside. When inserting the electrode this wire holds the tip in place. The electrode array itself is then retracted and thus positioned near the inner wall of the cochlea. This position is maintained by fixing the wire to the array. With the exception of electrode retraction and fixation, the surgical procedure is the same as with regular cochlear implantation.

The Cochlear Corporation (Melbourne, Australia) have developed the Nucleus 24 Contour Electrode. This elastic memory array holds 22 electrode contacts. The electrode must be straightened prior to insertion by using a stylet found inside the array. This stylet is then pulled back during insertion so that the electrode curls close to the inner wall of the cochlea. Different speech coding strategies can be used with this system.

In order to collect information concerning intracochlear electrode position and mechanism of trauma to cochlear structures the different types of perimodiolar electrodes were inserted in fresh human temporal bones. The bones were harvested within 16–18 h after death and implanted immediately with the cochlear implant electrodes. For all bones we used new electrodes and all implantations were performed by the same surgeon. The surgical procedure employed in this study was the same as that used for real implantations, i.e. the standard posterior tympanotomy–cochleostomy approach. All temporal bones were X-rayed and the insertion depth in terms of mm was calculated using a standard temporal bone X-ray technique (4).

Fixation was accomplished by perilymphatic perfusion of buffered formalin solution via the oval window. The temporal bones were incubated at 4°C for ≥ 24 h. The temporal bones with the electrodes still *in situ* were then embedded in polymethylmethacrylate, which permits sectioning of undecalcified bone using sawing and grinding. This histologic procedure has already been described by Plenk (5). In contrast to previous studies (6–8) the histologic procedure was performed in this study with the electrodes *in situ*. Standard cutting of the three specimen blocks in either the horizontal or saggital plane was performed and all bones were then stained in Giemsa solution.

Four different types of electrode were implanted: Clarion preformed electrode (2 bones), Clarion preformed electrode with positioner (1 bone), Nucleus contour electrode (1 bone) and Med-El Perimodiolar electrode C40 (2 bones).

RESULTS

Using the sawing, grinding and polishing technique, the inner ear structures as well as the electrodes could be clearly identified. We were able to evaluate electrode position and trauma to neighboring structures as well as insertion depth (in mm) from the X-rays.

The Clarion Preformed electrode was easy to straighten prior to insertion by using the insertion tool. However, a larger cochleostomy was necessary when compared with the Nucleus and Med-El electrodes. As can be seen from the histologic slide (Fig. 1), the electrode does not get very close to the modiolus and traumatizes the spiral lamina. In the middle turn of the cochlea, the electrode was found to be shifted towards the scala vestibuli.

The Clarion Preformed electrode with positioner could be clearly identified in the histologic slide (Fig. 2). The positioner covers the electrode along its whole length and the stimulating electrode gets close to the inner wall of the cochlea. This electrode showed a tendency to shift towards the scala vestibuli in the middle turn of the cochlea.

Fig. 1. Histologic slide showing Clarion Preformed electrode inserted into the scala tympani of a human temporal bone.

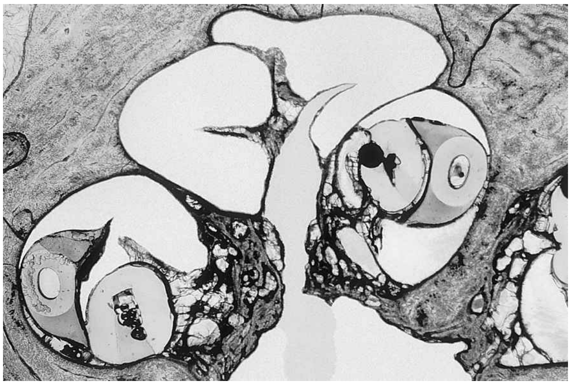

Fig. 2. Histologic slide showing Clarion Preformed electrode and positioner inserted into the scala tympani of a human temporal bone. The electrode has a clear perimodiolar position.

The Med-El PME C40 electrode could be inserted to a depth of 25–30 mm and was then retracted until the desired position was reached. X-rays of the temporal bones clearly demonstrated the perimodiolar position of the electrode contacts. The histologic temporal bone sections show the position of the electrode close to the modiolus (Fig. 3). The nitinol wire was found to be located close to the spiral ligament, with limited trauma to this structure. However, disruption of the spiral ligament seemed to increase in the direction of the apex of the cochlea.

The Nucleus Contour electrode was straightened by using the stylet inside the electrode carrier prior to implantation. The handling of this type of electrode was found to be very easy. A smaller cochleostomy was needed for the Contour implant as compared with the Clarion implant. However, examination of the temporal bones (Fig. 4) revealed the peripheral position of this type of electrode (first temporal bone preliminary result). In the basal parts of the cochlea

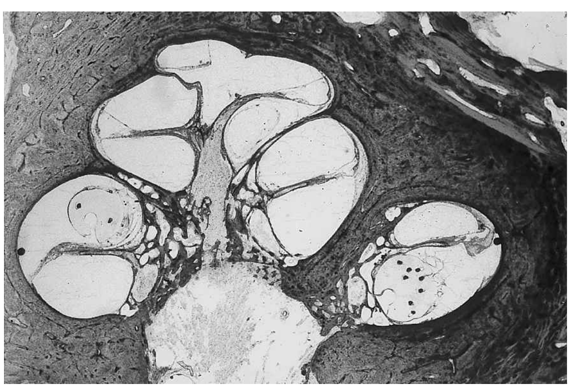

Fig. 3. Histologic slide showing Med-El PME C40 electrode inserted into the scala tympani of a human temporal bone. The electrode has a clear perimodiolar position, shifting into the scala vestibuli near its apex.

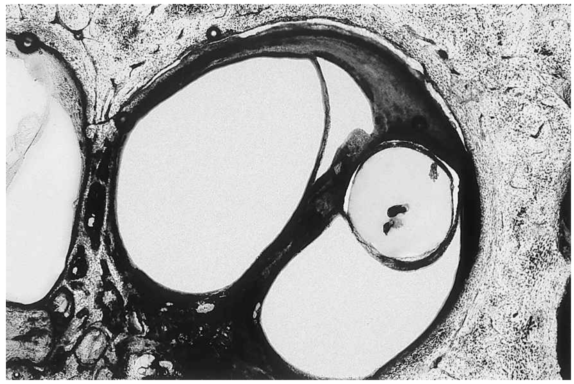

Fig. 4. Histologic slide showing Nucleus Contour electrode inserted into the scala tympani of a human temporal bone (preliminary result).

in particular the array lies closer to the outer wall of the cochlea (Fig. 4). Trauma to cochlear structures was minimal when using this device.

DISCUSSION

Perimodiolar electrodes have been developed by different companies in order to achieve lower thresholds for electrostimulation. The devices used in this study use different techniques to achieve perimodiolar electrode positioning. We also found differences in terms of insertion depth into the scala tympani, intracochlear electrode position and mechanism of trauma to cochlear structures. The histologic processing method, with cross-sections of the electrodes being evaluated *in situ*, proved to be a very effective technique, as the shape and position of these devices could then be identified easily.

The Clarion Preformed and Nucleus Contour electrodes were found to be similar to handle. Both are straightened prior to insertion. The Preformed electrode uses a straightening tool that is attached outside of the array. In contrast, the Contour model has to be inserted with a tool located inside the electrode carrier. This necessitates a larger cochleostomy for the Clarion implant. However, both devices showed no clear perimodiolar position. Using the Preformed electrode with the positioner increased the resulting trauma but the position within the scala tympani was close to the inner wall.

The PME C40 electrode is not yet in clinical use. The first prototype using a nitinol wire to achieve a perimodiolar position has been used in this study and in temporal bones only. Owing to the trauma caused in this study this electrode has subsequently been modified. The new electrode also features 12 contacts and consists of 2 segments which remain connected during insertion. Three-quarters of the electrode contacts are closely spaced and connect to the inner wall of the scala tympani in the basal turn. One-quarter of the contacts remain on the outer wall of the second turn. Positioning is realized by pulling back the electrode segment while holding the apical section of the device stationary with a restraining arm. The restraining arm is a non-active branch which stays on the lateral wall. The retracted length of the electrode can be 2–10 mm, depending on the original insertion depth. The surgeon has the option of positioning the electrode segment in the middle of the scala tympani. Embedded in the core of the restraining arm is a rectangular electrode which bends in the direction of the axis of the scala tympani and prevents deviation of the array towards the basilar membrane. An innovative design posterior to the cochleostomy causes the two branches of the array to remain aligned and parallel during and after the positioning phase. The final stage of the procedure involves clamping the two segments of the electrode with a titanium clip. Further examinations using the new Med-El device in human temporal bones are necessary before this electrode can be used in human cochlear implantations.

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Address for correspondence:
Wolfgang Gstoettner, MD
Department of Otolaryngology
JW Goethe University Frankfurt/Main
Theodor Stern Kai 7
DE-60590 Frankfurt/Main
Germany
Tel.: +49 69 6301 5163
Fax: +49 69 6301 5435