coil section than the present mini-implant, there is a need to rotate it more superiorly so there is an ample area of skull for it to abut against and so have support. This has meant making the inverted-U skin incision reach higher than for the present mini device. The incision is still made through the subcutaneous tissue down to the epicranial aponeurosis and pericranium (periosteum). The skin and periosteum are raised as separate flaps. The mastoid extenteration is made sufficient for access for the posterior tympanotomy and exposure of the round window. Care is taken to remove enough cells over the sigmoid sinus posterosuperiorly so the electronic package can sit without protrusion of the pinna.

As stated above, it is desirable to place the receiver coil more superiorly than with the mini device. This means drilling over the posterior root of the zygoma and floor of middle fossa. In the adult this step can be made without exposure of dura, but dura would be exposed in young children. The electrode insertion is carried out in the usual way, and the package is placed as shown in Fig 1B prior to inserting sutures over it to hold it in place.

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INVESTIGATIONS ON A CURVED INTRACOCHLEAR ARRAY

M. J. DONNELLY, MB, FRCSI; L. T. COHEN, PhD; J. XU, MD; S.-A. XU, MD; G. M. CLARK, PhD, FRACS

From the Human Communication Research Centre, University of Melbourne (Donnelly, Cohen, S.-A. Xu, Clark), and the Cooperative Research Centre for Cochlear Implant, Speech and Hearing Research (J. Xu, Clark), Melbourne, Australia.

INTRODUCTION

The electrode array of a multiple-channel cochlear implant lies against the outer wall of the scala tympani. From this position electrical current spreads to excite residual neural elements, particularly spiral ganglion cells within the modiolus. It is not clear whether the spread of current from the outer wall is optimal for multiple-channel speech processing, but placement closer to the target nerves could result in lower thresholds. This could have benefits through the use of shorter pulse durations and extended battery life. Computer modeling studies and animal experiments have suggested that for localized current the optimal electrode position is adjacent to the modiolus.

At the University of Melbourne it was felt that an electrode with a curve matching the internal cochlear spiral would remain close to the modiolus after insertion. A curved electrode was developed and an inserting tool was designed and produced (Treaba et al, this suppl, this section). Preliminary studies suggested that the electrode array did indeed remain close to the modiolus. Before further development of this type of electrode design, it was necessary to determine whether modifications to the surgical technique for its insertion were required. It was also important to ensure that the curved electrode fabricated for clinical trial would lie closer to the modiolus than to the outer wall of the scala tympani. This study was undertaken to examine these issues.

METHODS

Five human cadaver temporal bones were implanted with the curved electrode within 16 hours of death, by means of the inserting tool designed specifically for the purpose (Fig 1). The same surgeon, with experience in cochlear implantation,
performed all the insertions. Details regarding the relative size of the mastoidectomy, tympanotomy slot, and cochleostomy and the ease of insertion were recorded. After implantation the bones were submitted to radiography to determine the position of the electrode within the cochlea. The radiographs were analyzed to calculate the insertion angles of the individual bands of the array and their radial distances from the modiolus. A modification of the technique described by Marsh et al. was used. This modified technique requires digitization of the positions of two anatomic reference points in addition to the positions of the individual electrode bands. The reference points are the tip of the superior semicircular canal and the approximate center of the vestibule. A line between these two points defines a reference axis. A mathematical spiral shape is fitted by computer to the positions of the electrode bands, thus determining the center of the spiral, which approximates the position of the modiolus. The angles of the electrode bands can then be calculated about the spiral center, with 0° corresponding to a line drawn perpendicularly from the center to the reference line (Fig 2). The mathematical shape used was obtained from measurements of the radiographs of 25 patients implanted with the standard Cochlear Pty Limited array.

Digitized images of 12 Silastic (Dow Corning) silicone rubber molds of human scala tympani were analyzed to determine the mean positions of the inner (modiolus) and outer walls of the scala tympani. Each mold was aligned with the base toward the camera and with the hypothetical modiolar axis aligned visually with the axis of the lens. After capture of the image, it was rotated until the position of the round window corresponded to the mean angle determined by analysis of radiographs of electrode arrays implanted through the round window. The center position for each mold, common to the spirals of both the inner and outer walls, was estimated visually and accepted, subject to regular variation of radial distance with rotational angle about that center. Taking the mean of 12 molds resulted in a very regular variation of distance with angle. Radial distance was measured at intervals of 45°, from 45° to 540°.

Fig 4. Mean outer and inner walls of 12 Silastic silicone rubber (Dow Corning) molds of scala tympani, shown as solid and dashed lines, respectively. Data are presented in two ways, pictorially on left and as radial distance versus angle on right. In right figure, bounds of ±2 SD are given as dotted lines.
In order to estimate the position of each implanted electrode array relative to the inner and outer walls of the scala tympani, the reconstituted radiograph for the relevant temporal bone was superimposed on a graphic representation of the mean wall data from the Silastic molds, as determined above.

One temporal bone was filled with resin after implantation to fix it in position. The bone was sectioned undecalcified in the middle electrode position, to show the position of the electrode array with respect to the inner and outer walls of the scala tympani.

RESULTS

All five curved electrode arrays were successfully and fully inserted without difficulty. The mastoidectomy and tympanotomy slot were no different from those presently used for implantation. In four of the bones the corda tympani was preserved. The cochleostomy required was 1.2 to 1.3 mm in diameter to accommodate the introduction of the inserting tool into the basal turn. Once in place, the electrodes did not require further fixation.

The plain radiographs of the implanted bones revealed a gap between the outer wall of the cochlea and the electrode array. This is illustrated in Fig 2, in which the visible sections of both the outer and inner walls are indicated by dashed lines. Computed analysis of the digitized radiographs provided the electrode band positions for each electrode array. The mean radial distance for all five arrays is plotted as a function of angle in Fig 3. Pictorial and graphic representations of the mean positions of the inner and outer walls of the scala tympani, determined from analysis of Silastic molds, are shown in Fig 4. The mean position of the electrode array is demonstrated by superimposing Fig 3 on Fig 4. Thus, in Fig 5, it can be seen that the curved array generally lies midway between the modiolus and the outer wall of the scala tympani. Toward the apex it is closer to the outer wall, and near the cochleostomy it lies closer to the modiolus.

The section of the undecalcified bone was taken at the middle electrode region and demonstrated the curved electrode array to lie midway between the inner and outer walls of the scala tympani (Fig 6).

DISCUSSION

One of the factors limiting speech perception achieved by patients with cochlear implants could be the extent of neural excitation produced when each electrode band is activated. The extent of current spread could depend on the mode of stimulation and the distribution and resistances of anatomic structures. As electrical current spreads radially from the electrode, the greater the distance between the array and the target spiral ganglion cells within the modiolus, the greater the neural region stimulated. Computer modeling studies of the electrical voltage distributions from electrodes in the cochlea have predicted that placing electrodes closer to the modiolus reduces the longitudinal spread of excitation.\(^2\,^3\)
a cat model it was demonstrated that placing a banded array adjacent to the modiolus could result in a reduction of stimulation thresholds and an increase in the dynamic ranges of electrode pairs. Such changes could improve speech perception in cochlear implant patients.

A precurved electrode array was designed at the University of Melbourne to remain close to the modiolus after insertion. To insert the electrode array it was necessary to design an inserting tool that would hold the array in a straight configuration to allow it to be introduced into the cochlea. Preliminary work on skeletonized cochleas showed that the inserting tool must be introduced into the cochlea for a distance of 6 mm before attempting to release the electrode. Beyond this distance the inserting tool would impinge on the wall of the scala tympani. Releasing the electrode before it was inserted 6 mm resulted in the array's curling back on itself and not ascending around the cochlear spiral. There was some concern that using the inserting tool within the confines of a standard mastoidectomy and tympanotomy slot would present difficulties. Our study has shown that the standard mastoidectomy is acceptable. However, anatomic variations may be relevant in particular situations. A very anteriorly placed sigmoid sinus may restrict access, but as in endolymphatic sac surgery, this can be overcome by exposing and decompressing the venous sinus.

The posterior tympanotomy slot did not require any special modification. In four of five bones it was possible to preserve the corda tympani. Local anatomy in individual cases would determine the ability to preserve this nerve, and obviously, patients would need to be warned of potential taste disturbances. The main feature requiring modification was the size of the cochleostomy. As the maximum external diameter of the straight array is 0.64 mm, the cochleostomy can be less than 1 mm in diameter. The external diameter of the inserting tool is 1.1 mm, and therefore, a cochleostomy of 1.2 to 1.3 mm was found to be necessary for manipulating the inserting tool and preventing it from getting stuck in the cochleostomy. Such a generous opening allows the surgeon a view of the modiolus and an appreciation of the takeoff of the spiral. This is important in helping to align the inserting tool in the correct orientation before releasing the electrode.

From the plain radiographs of the implanted temporal bones it appeared that the curved electrode array was lying away from the outer wall of the scala tympani. Our determination of the mean position of the electrode array within the scala tympani was based on analysis of these radiographs, and on mean inner and outer wall positions derived from analysis of 12 Silastic molds of the scala tympani. There were a number of approximations made in the analysis, and therefore the results obtained are not absolute. Nonetheless, our results show that the curved array assumes a position generally midway between the modiolus and the outer wall of the scala tympani, with some variation at the apical region of the array, further from the modiolus, and also near the cochleostomy, closer to the modiolus. The section of the temporal bone with the electrode fixed in situ also provides evidence of the midscalar location of the curved electrode array.

The extent of insertion trauma is being addressed, and the temporal bones used in this study are being subjected to histologic examination. While the position of the curved electrode array is markedly closer to the modiolus than that of the straight array, it can be improved. Modification of the curve may allow the electrode to be placed closer to the modiolus. It must be emphasized, however, that at this stage there is no evidence that speech results would be better with that array, and further research is needed to establish this.

SUMMARY
A curved electrode array and inserting tool have been developed at the University of Melbourne. This electrode array can be successfully implanted with few modifications to the surgical procedure presently in use. When implanted, the curved electrode array adopts a position closer to the modiolus than does the standard straight electrode array.

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POSTIMPLANTATION MENIERE'S SYNDROME WITH FLUCTUANT ELECTRICAL THRESHOLDS
S. S. GRAHAM, MS; J. R. E. DICKINS, MD
From the Ear & Nose-Throat Clinic, P.A., Little Rock, Arkansas.

A 42-year-old patient with a history of ototoxically induced profound sensorineural hearing loss experienced a sudden onset of Meniere's-like syndrome 16 weeks after implant surgery and 6 weeks after beginning full-time device usage.