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Main Article

Preservation of residual hearing following cochlear implantation: comparison between three surgical techniques

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Abstract

The preservation of residual hearing is becoming a high priority in cochlear implant surgery. It allows better speech understanding and ensures long-lasting and stable performance; it also allows the possibility, in selected cases, of combining electro-acoustic stimulation in the same ear.

We present the results of a retrospective study of the conservation of residual hearing in three different groups of patients who had undergone cochlear implantation using three different cochlear implant electrode arrays, combined with three different surgical techniques for the cochleostomy. The study aimed to evaluate which approach allowed greater preservation of residual hearing.

The best residual hearing preservation results (i.e. preservation in 81.8 per cent of patients) were achieved with the Contour Advance electrode array, using the Advance Off-Stylet technique and performing a modified anterior inferior cochleostomy; this combination enabled reduced trauma to the lateral wall of the cochlea during electrode insertion.

Key words: Cochlear Implants; Sensorineural Deafness; Otologic Surgical Procedures

Introduction

Cochlear implantation has traditionally been used for auditory recovery in patients affected by profound, bilateral perceptive hearing loss whose speech perception no longer benefits from hearing aid use. As a result of the remarkable word recognition scores enabled by cochlear implantation, over the last few years the indications for this procedure have been widened, to include patients with some degree of residual hearing and limited speech understanding with hearing aid use (up to 50–60 per cent according to the last USA Food and Drug Administration guidelines).[1] Moreover, pre-operative residual hearing has been shown to be a positive predictor of good performance following cochlear implantation.[2–6] Recently, indication criteria have been extended to include patients who have not traditionally been considered as cochlear implant candidates. These patients are characterised by having severe or profound hearing losses only at frequencies at or greater than 1 kHz, with near normal or only mildly diminished hearing in the low frequencies.[7–11] Therefore, there is now the need to perform atraumatic surgery using 'soft' electrodes and surgical techniques, in order to preserve residual hearing in such patients.

The aim of such atraumatic surgery is to reduce the risk of damage to cochlear structures, such as the basilar membrane, spiral osseus lamina and modiolar wall, and also to minimise ossification and fibrosis of these structures, in order to preserve residual hearing.

In patients with preserved residual hearing at the low frequencies (i.e. up to 1 kHz), a hearing aid plus electro-acoustic stimulation can confer advantages (compared with traditional electrical stimulation provided by the cochlear implant alone), such as better speech perception abilities (especially in the presence of background noise) and better music appreciation.[7–11]

In this paper, we present the results of a retrospective study of conservation of residual hearing in patients who had undergone cochlear implantation with the Nucleus 24 cochlear implant in our ENT unit. All the patients with detectable pre-operative residual hearing at low frequencies were audiologically evaluated and divided into three groups according to the surgical approach used and the type of electrode inserted.

Group one had undergone insertion of a Nucleus 24 M-K standard electrode array, through a classic round window cochleostomy. Group two had received a Nucleus 24 Contour electrode array, using the 'soft surgery' technique.[12] Group three had received a Nucleus 24 Contour Advance electrode array, via a modified antero-inferior

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cochleostomy near the round window niche (1 mm from the crista fenestrae) using the Advance Off Stylet technique.[13] The choice of the surgical technique and the electrode inserted related to the evolution in both, over the years of the study (1998–2005).

The aim of this study was to assess the various combinations of the three different surgical techniques and the three different electrode array designs used, and to evaluate which combination allowed the best preservation of residual hearing.

Materials and methods

We evaluated retrospectively 30 out of 86 patients who had undergone cochlear implantation in our clinic, using different models of the Nucleus 24 cochlear implant (Cochlear Corporation, Lane Cowe, Australia), from 1998 to 2005. Patients were selected based on the presence of some degree of residual hearing at low frequencies (up to 1 kHz) before implantation. We excluded from the study: patients with hearing loss progression during the year prior to cochlear implantation; children (i.e. younger than 15 years) who did not correctly respond to acoustic signals with a difference of 5 dB; those with cochlear ossification or obstruction, or cochlear malformations; and those in whom different or inadequate surgical techniques had been used. We also excluded patients who had an open set word recognition score worse than 10 per cent when using the hearing aid in the candidate ear.

The 30 patients enrolled for the study were divided into three different groups, depending on the type of implant and the surgical approach which had been used. In the first group, the Nucleus 24 M-K electrode array had been introduced via a classic round window cochleostomy. In the second group, the Nucleus 24 Contour electrode array had been introduced via the soft surgery technique.[12] In the third group, the Nucleus 24 Contour Advance electrode array had been introduced via a modified antero-inferior cochleostomy near to the round window niche, using the Advance Off-Stylet technique, proposed by the implant manufacturer.[13]

Group one comprised eight patients, two females and six males (mean age at implantation, 30.25 years; range, 23–39 years). Group two comprised 11 patients, six females and five males (mean age at implantation, 29.6 years; range, 15–75 years). Group three comprised 11 patients, two females and nine males (mean age at implantation, 29.7 years; range, 15–55 years).

Pre-operatively, all the patients had undergone a complete audiological evaluation, including: an accurate anamnestic personal and family history; otoscopic and otomicroscopic evaluation; pure tone audiometry (both for air and bone conduction); speech audiometry; speech perception test with a hearing aid in the candidate ear (in order to evaluate patients' word recognition score without lip reading[14]); tympanometry with stapedial reflex study; auditory evoked brainstem responses; otoacoustic emissions; and an aetiological study (according to a previously published protocol,[15] including molecular analysis for connexin 26 and 30 and mitochondrial deoxyribonucleic acid mutations and deletions (including the A1555G and A3243G point mutations)). Each patient had also undergone a neuroradiological study (using high resolution computed tomography) of the petrous bone, together with a magnetic resonance imaging scan of the brain, the VIIIth nerve and the inner ear, in order to exclude the presence of inner-ear malformations, cochlear obstruction or ossification, or auditory nerve morphological abnormalities.

Following surgery, evaluation of residual hearing had been carried out using the same audiometer (an Amplaid 460; Milan, Italy) as for the pre-operative evaluation, using steps of 5 dB, from six to 48 months after cochlear implantation. To any frequency threshold over the maximum output limit of the audiometer, we assigned a value 5 dB greater than the maximum output level (i.e. 105 dB for 0.25 kHz, 125 dB for 0.5 and 1 kHz). Any vibrotactile sensation was excluded.

Some of the patients included in the study had not demonstrated measurable residual hearing when tested at 2, 4 and 8 kHz. We had therefore calculated the pure tone average (PTA) pre- and post-operatively, including only the low to medium frequencies (i.e. 0.25, 0.5 and 1 kHz).

Pre-operatively, patients' low-medium frequency mean PTA was 100 dB HL in group one, 100.7 dB HL in group two and 98 dB HL in group three.

Post-operatively, we calculated the mean post-operative deterioration in the low to medium frequency PTAs for each group. We also calculated, for each group, the percentage of patients in whom residual hearing had been completely preserved (i.e. $<$10 dB difference between pre- and post-operative PTAs), partially preserved (i.e. 10–20 dB difference between pre- and post-operative PTAs), worsened (i.e. $\geq$20 dB difference) or totally lost. We grouped those with totally lost or worsened residual hearing in the same category, as the amount of pre-operative residual hearing in our patients was limited and so a post-operative deterioration of $\geq$20 dB was considered important.

We also calculated, separately for each group, the mean deterioration of thresholds for each measured frequency (i.e. 0.25, 0.5 and 1 kHz).

Surgical technique

In all the 30 patients selected, we used standard length Cochlear Corporation electrodes: 25 mm for the Nucleus 24 M-K, and 19 mm for both the Nucleus 24 Contour and the Nucleus 24 Contour Advance (the latter with Softip). Surgery had been conducted by the same otological surgeon (SB), an expert in cochlear implant surgery, in order to reduce trauma and technical variation.

In group one, a classic cochleostomy via the round window was performed. In group two, following the soft surgery approach proposed by Lehnhardt,[12] the cochleostomy (of 1–1.2 mm) was performed 2 mm anterior to the round window niche, opening the endostium after completing bone milling (Figure 1).

In group three, a modified antero-inferior cochleostomy of approximately 1–1.2 mm diameter

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was performed near the round window, at the crista fenestrae (Figure 2). The bone overhanging the niche was drilled to enable complete visualisation of the round window membrane. The cochleostomy was created using a small, 1–1.2 mm diamond burr, at low speed, applied anteriorly and inferiorly to the round window, about 1 mm from its annulus. After bone drilling was completed, the endostium was opened. Once the cochlea was opened, great attention was paid to avoiding suction of the perilinfa and contamination by bone dust or blood. In group three, the Advance Off-Stylet technique[13] proposed by the implant manufacturer was used to introduce the electrode, in order to avoid significant contact with the lateral wall of the cochlea. According to this technique, the array, held straight by a stylet, was angled toward the floor of the scala tympani and the half bands electrodes were oriented toward the modiolus. The array was inserted around 8.5 mm into the cochleostomy hole, as indicated by a marker dot placed on the electrode; the stylet was then held stationary while the electrode array was advanced off the stylet and into the cochlea until the third (most proximal) rib was at the cochleostomy. In this way, the electrode array, entering the inferior and lateral portion of the scala tympani, followed the curvature of the cochlea around the modiolus, minimising trauma to the lateral wall.[11,16,17] The electrode insertion length was approximately 17–19 mm, leaving the three ribs placed externally. The cochleostomy was carefully closed using strips of temporal fascia and fragments of temporal muscle and fibrin glue. In all patients, care was taken to leave the ossicular chain intact.

The 30 patients studied had suffered no surgical complications, and all the electrodes had been introduced into the cochlea without difficulty. Moreover, all patients had shown good results on intra-operative telemetry testing, including, when available, neural response telemetry.

Cephalosporin group antibiotics had been given intravenously intra-operatively and then post-operatively for seven days in all patients.

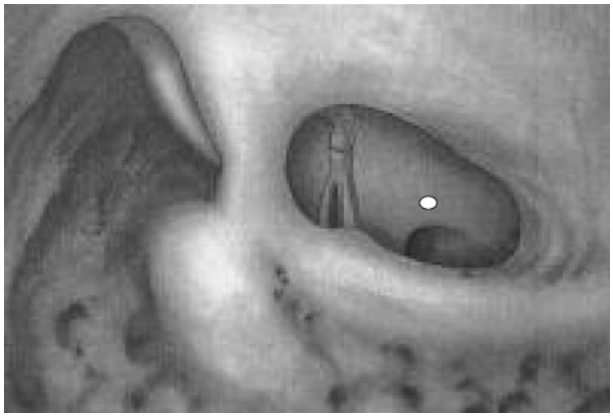

FIG. 1

Cochleostomy of approximately 1–1.2 mm diameter (white oval), performed 2 mm anteriorly to the round window niche, according to the 'soft surgery' technique.

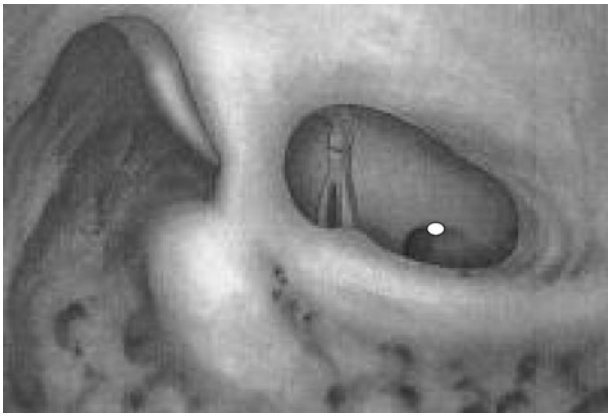

FIG. 2

Modified antero-inferior cochleostomy (white oval), at the crista fenestrae, approximately 1–1.2 mm in diameter.

After implantation, each patient had undergone an X-ray study using a modified Stenver's or 'cochlear' view,[18] in order to check that the electrode's position and insertion depth were correct.

Results

Post-operatively, we found a mean pure tone average at low to medium frequencies of 115.4 dB HL in group one, 113.3 dB HL in group two and 109.3 dB HL in group three (see Table I). The mean low to medium frequency PTA worsened by 15.4 dB in group one, by 12.6 dB in group two and by 11.3 dB in group three (see Table I).

In group one, residual hearing at low to medium frequencies was completely preserved in only one patient (12.5 per cent), partially preserved in one of eight patients (12.5 per cent) and totally lost (or worsened by >20 dB) in six of eight patients (75 per cent).

In group two, residual hearing at low to medium frequencies was completely preserved in three of 11 patients (27.3 per cent), partially preserved in two of 11 patients (18.2 per cent) and totally lost (or worsened by >20 dB) in six of 11 patients (54.5 per cent).

In group three, residual hearing at low to medium frequencies was completely preserved in six of 11 patients (54.5 per cent), partially preserved in three of

TABLE I

MEAN PRE- AND POST-OPERATIVE PTA* AND PTA DETERIORATION, BY PATIENT GROUP

Parameter	Grp 1	Grp 2	Grp 3
*PTA**			
Mean pre-op (dB HL)	100	100.7	98
Mean post-op (dB HL)	115.4	113.3	109.3
Mean deterioration (dB HL)	15.4	12.6	11.3
*Residual hearing preservation**			
Complete (%)	12.5	27.3	54.5
Partial (%)	12.5	18.2	27.2
Total loss (%)	75	54.5	18.2

*At 0.25, 0.5 and 1 kHz. Grp = group; PTA = pure tone average; pre-op = pre-operative; post-op = post-operative

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TABLE II

MEAN HEARING THRESHOLD DETERIORATION, BY GROUP

Frequency (kHz)	Hearing threshold deterioration (dB)		
	Grp 1	Grp 2	Grp 3
0.25	10	12.3	9.2
0.5	20	16.4	11.7
1	16.25	15	13.2

Grp = group

11 patients (27.2 per cent) and totally lost (or worsened by >20 dB) in two of 11 patients (18.2 per cent).

Table II shows the mean post-operative threshold deterioration at 0.25, 0.5 and 1 kHz, for each group.

Discussion

Recent extension of the indications for cochlear implantation, to include children and patients with residual hearing, has made the preservation of residual hearing a high priority in implantation surgery. Residual hearing allows the patient to have better speech understanding and also ensures long-lasting and stable cochlear implant performance. Following cochlear implantation, the preservation of residual hearing also allows the possibility of combining electro-acoustic stimulation within the same ear; this combination has been reported to enable substantially improved speech perception, hearing in noise and music appreciation.[7–11] Therefore, preservation of any residual hearing must be a goal of cochlear implantation surgery.

The insertion of electrode arrays into the cochlea can potentially damage cochlear structures. Histological evaluations have found evidence of trauma resulting from the insertion of cochlear implant electrodes, in the form of damage to the spiral ligament, basilar membrane, osseous spiral lamina and other structures. There is general agreement that damage to the osseous spiral lamina, basilar membrane and Reissner's membrane results in localised loss of spiral ganglion cells, and that the extent of neural damage is proportional to the degree of cochlear tissue injury.[6] An atraumatic insertion of the electrode array is necessary in order to prevent damage to cochlear structures and subsequent possible degeneration of neural tissue; however, it is not certain that the loss of ganglion cells has an adverse effect on rehabilitation results.[19]

The loss of residual hearing during implantation is the result of a combination of factors, including the technique used to create the cochleostomy as well as the characteristics of the electrode array itself (such as its diameter, stiffness and length) and the insertion manoeuvre used. Moreover, insertion trauma can cause new bone formation and fibrosis within the scala tympani; opening the cochlea also creates a portal of entry for infections, potentially leading to infectious labyrinthitis.[17] Therefore, in order to cause minimal trauma to cochlear structures, surgeons should in principle use smooth, atraumatic electrode carriers and adapted surgical procedures.[7–11,17,19,20] These issues are currently under debate, because of our limited knowledge of factors actually responsible for hearing preservation or loss.

In this regard, many histological studies have evaluated the effects of: different electrode arrays (and subsequent damage to cochlear structures); different surgical approaches to the scala tympani; and different electrode insertion techniques.[19,21–27] Recent papers have focused on comparing the degree of cochlear damage from straight versus perimodiolar arrays.[24,27]

A recently developed and widely used grading system to evaluate the extent of cochlear trauma, published by Eshraghi *et al.* in 2003, is shown in Table III.[23] This system appears to be a valid method of assessing implant insertion trauma to cochlear structures within human temporal bones, thus enabling comparison of results.

Many authors have described a higher degree of trauma to the fine cochlear structures following the use of Clarion perimodiolar electrode arrays, in comparison with other perimodiolar and straight arrays.[19,21,24,25] In 2001, Gstoettner *et al.* assessed the use of Clarion perimodiolar electrodes (i.e. the Clarion preformed electrode and the Clarion preformed electrode with positioner) in fresh human temporal bones, and found that both implants traumatised the spiral lamina and shifted towards the scala vestibuli (i.e. causing grade three lesions, by the Eshraghi grading system),[23] with the Clarion preformed electrode with positioner lying closer to the inner wall of the cochlea.[25] Gstoettner *et al.* observed a lesser degree of trauma following insertion of the Med-El perimodiolar and Nucleus Contour arrays (grade zero to one lesions by the Eshraghi system).[23,25] In addition, Aschendorrf *et al.*, in a 2003 study using fresh temporal bones, confirmed the high degree of cochlear trauma (grades three to four by the Eshraghi system) following insertion of the Clarion preformed electrode.[19]

The lesser degree of insertion trauma caused by straight electrodes was confirmed by Adunka *et al.* in a recent (2004) paper assessing the effects of Med-El electrodes.[21] These authors used the C40+ electrode and the Flex electro-acoustic stimulation electrode, designed to enable a shallower insertion depth and thus to assist preservation of residual hearing. The extent of cochlear trauma, following insertion of the electrode arrays through the round window membrane, was evaluated in eight fresh human temporal bones. Adunka *et al.* found that

TABLE III

SYSTEM FOR GRADING DAMAGE TO COCHLEAR STRUCTURES

Grade	Histopathological changes
0	No trauma
1	Elevation of basilar membrane
2	Rupture of basilar membrane or spiral ligament
3	Dislocation into scala vestibule
4	Fracture of osseus spiral lamina or modiolar wall

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the scala tympani insertions were deep and atraumatic (grades zero, one and three by the Eshraghi system) and that significant basal trauma occurred in only one of the temporal bones (in which grade four lesions were observed).[21] They also found a lesser degree of trauma in comparison with bones implanted using a cochleostomy approach.[21]

Richter *et al.*, in a 2001 paper, compared the cochlear damage sustained by the Cochlear Corporation Nucleus standard straight electrode array and the Nucleus Contour electrode array, using 29 fresh frozen bones.[24] They found that intracochlear insertion of the straight array was less traumatic. Following insertion of the Nucleus Contour electrode, using a standard cochleostomy size and site (i.e. anterior to the round window), they observed localised basilar membrane penetration (grade two lesions by the Eshraghi system).[23] However, when using a slightly larger cochleostomy (about 1.8 mm) situated closer to the round window, and employing a partial stylet withdrawal while inserting the electrode, they found a lower rate of cochlear trauma, compared with other electrode arrays.[24]

However, in a 2005 paper, Wardrop *et al.* did not report any significant difference regarding the degree of insertion trauma sustained in cadaver temporal bones following insertion of the Nucleus Contour and the standard Nucleus straight electrodes.[27] These authors also demonstrated that the Contour electrode array allowed an insertion which was deeper and closer to the modiolus, compared with the straight electrode.[27]

Klenzner *et al.*, in 2004, reported minimal cochlear insertion trauma in human temporal bones, using the Nucleus Contour Advance array and a standard insertion technique.[28]

In 2003, Eshraghi *et al.* reported a variable degree of cochlear trauma, ranging from grade zero to four, following insertion of three different perimodiolar electrode arrays in human cadaver temporal bones: the Combi 40+ PM (Med-El), the HiFocus II (Advanced Bionics) and the Contour (Cochlear Corporation). These authors did not find any statistically significant difference in the degree of cochlear trauma caused by the three electrodes.[23]

The results obtained by these various authors' histological studies using human temporal bones are variable. This is probably related to the variety of surgical techniques adopted and also to the different ways in which the human temporal bones were used (which may have introduced some artefacts). However, from a review of the literature, we can deduce that straight arrays (i.e. those by Med-El and the Cochlear Corporation, including the Nucleus Contour Advance array with softip) generally appear to cause less trauma to cochlear structures.[21,24,28] With regard to surgical technique, the above histological studies seem to indicate that performing a cochleostomy antero-inferior to the round window, or a fenestral cochleostomy, produces a lesser degree of trauma to the fine cochlear structures.[21,24,27,28]

In recent years, many clinical studies have reported on the preservation of residual hearing following cochlear implantation. Different surgical approaches and different electrode array designs have been used in an attempt to prevent damage to the anatomical structures of the cochlea.[7–10,17,20,29–31]

As early as 1987, Dye *et al.* retrospectively evaluated the preservation of residual hearing in 20 patients undergoing cochlear implantation, using a classical cochleostomy and an approximately 6 mm long electrode (3M/House, Los Angeles, California). They achieved partial preservation of hearing in eight of 20 patients (40 per cent), a relatively high success rate, probably due to the reduced length of the electrode. In 1993, Lehnhardt introduced the concept of soft surgery to minimise trauma to cochlear structures.[12] The same author subsequently conducted a retrospective study on 12 children implanted with a Cochlear Corporation electrode (22 mm long) with a limited insertion and a minimal cochleostomy (2 mm), using the soft surgery technique.[32] In this series, perilymph was preserved and hyaluronic acid was used while inserting the electrode.[32] Residual hearing was preserved in 50 per cent of patients.[32]

Lehnardt's results were later confirmed, by Hodges *et al.* in 1997 (using Nucleus and Clarion electrodes),[29] and one year later by Fraysse *et al.* (using Nucleus electrodes[30] and the soft surgery technique).[32]

Improved electrode design, and careful and less traumatic surgery, have led to a significant improvement in residual hearing preservation following cochlear implantation surgery. Recent studies have shown that residual hearing can be preserved in a good percentage of cases if the operating surgeon focuses on minimising surgical trauma while opening the cochlea and inserting the electrode array. However, even if great care is taken, residual hearing is completely lost in about 20 per cent of implant recipients.[7–11,20] The results reported in the present study confirm these data – in group three, using an atraumatic surgical technique, we achieved preservation of residual hearing in 81.8 per cent of patients.

In addition to performing soft surgery while opening the cochlea, some authors have focused on controlling the insertion depth in order to minimise trauma to fine cochlear structures and subsequently to achieve better residual hearing preservation. The assumption is that a shorter insertion depth is less likely to damage residual hearing.[7–11,20] In this regard, Gstoettner *et al.*[9] published in 2004 a study of 21 patients implanted using an atraumatic electrode insertion procedure, performing the cochleostomy anterior to the round window and controlling the insertion depth (360°, 18–24 mm), using the Combi 40+ Medium electrode array and the standard length Combi 40+ electrode array by Med-El (with electrode contact distribution lengths of 22 mm and 26.4 mm, respectively). These authors succeeded in preserving low frequency residual hearing in 18/21 patients (85.7 per cent).[9] In the same year, Kiefer *et al.* reported use of the same surgical technique and electrode arrays, with similar results, preserving residual low frequency hearing in 12/14 patients (86 per cent).[20]

Gantz and Turner, of the Iowa group, published two recent studies (2003 and 2005) in which 'shorter'

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insertions were performed, using reduced length electrodes, in order to minimise trauma to the apical cochlear structures.[7,8] They used six channels, with 6 or 10 mm short arrays, derived from the Nucleus 24 cochlear implant, and achieved residual hearing preservation in the majority (96 per cent) of subjects.[7,8] This demonstrated that the Nucleus short electrodes were successful in preserving low frequency hearing and providing sufficient additional high frequency information to improve speech perception.[7,8]

In a recently published European multicentre study, James *et al.* (2005)[11] and subsequently Fraysse *et al.* (2006)[10] evaluated conservation of residual hearing after implantation with a standard length Nucleus Contour Advance electrode array in 27 adult patients. Twelve of the 27 patients underwent surgery according to a defined soft surgery protocol; specifically, the surgeons performed a 1–1.2 mm cochleostomy hole, anterior and inferior to the round window, using the Advance Off-Stylet Technique. They also controlled the insertion depth, leaving three of the square marker ribs outside the cochleostomy hole. The insertion depth varied from 300° to 430°, despite modest variations in the length of the electrode inserted (17–19 mm). The best results, in terms of residual hearing preservation, were achieved in the 12 patients operated upon using the soft surgery technique; they had a preservation rate of 75 per cent.[10,11]

- **A retrospective study compared preservation of residual hearing after cochlear implant surgery in three groups of patients, using three different electrode arrays combined with three different surgical techniques**
- **Best results (i.e. preservation of residual hearing in 81.8 per cent of patients) were achieved via a modified anterior inferior cochleostomy, inserting the Contour Advance electrode array using the Advance Off-Stylet technique**
- **A cochleostomy antero-inferior to the round window niche minimises trauma to the fine cochlear structures during electrode array insertion**

In the present paper, we observed a higher percentage of total loss of residual hearing in group one (75 per cent, six of eight patients); these patients underwent standard straight electrode insertion (i.e. Nucleus 24 M-K), with the cochleostomy at the level of the round window. This result is probably related to the site of the cochleostomy hole, which does not allow a direct approach to the scala tympani and causes a high percentage of rupture of the spiral ligament and fractures of the osseous spiralis lamina. Moreover, in these patients, we did not use the soft surgery approach and the insertion length was not controlled, resulting in a higher degree of cochlear structure damage.

In group two, patients received a 1–1.2 mm cochleostomy, 2 mm anterior to the round window niche, using the soft surgery approach, with implantation of a Contour electrode array. Partial or total preservation of residual hearing was found in 45.5 per cent of patients, with a mean post-operative pure tone deterioration at the low to medium frequencies (0.25, 0.5 and 1 kHz) of 12.6 dB. These results confirm the utility of the soft surgery technique.[12]

We achieved the best results in group three patients, who were implanted with a standard length Contour Advance electrode array via a modified anterior inferior cochleostomy. This electrode array and cochleostomy technique were similar to the approach used in the above-mentioned European multicentre study of Fraysse *et al.*[10,11] In this group of patients, rates of residual hearing preservation were similar to those reported by Kiefer *et al.*,[20] Fraysse *et al.*[10] and James *et al.*[11] By performing a cochleostomy anterior and inferior to the round window at the crista fenestrae, using the Advance Off-Stylet technique and controlling the insertion depth, we obtained residual hearing preservation in nine of 11 patients (81.8 per cent), with a mean deterioration of hearing threshold at 0.25, 0.5 and 1 kHz of 11.3 dB. However, it must be noted that our data are not completely comparable, as the amount of residual hearing at the low to medium frequencies was less than that reported in the above-mentioned studies. It should be noted that, in our experience, Italian-speaking patients with a higher degree of residual hearing at frequencies below 1 kHz perform well with hearing aids and are not usually candidates for cochlear implantation; for this reason, our study included no patients with mild to moderate hearing losses at these frequencies.

We believe that reduction in the degree of cochlear damage, and consequent maximal residual hearing preservation, are related to both the electrode array design (a softip design being especially effective in reducing trauma to the lateral cochlear wall structures during insertion) and the surgical technique used. The size and site of the cochleostomy are chosen to reduce trauma while drilling and inserting the electrode. In particular, a cochleostomy site anterior and inferior to the round window niche allows a straight path to the inferior part of the basal turn of the scala tympani and avoids the osseous spiralis lamina, reducing trauma to the spiralis ligament. Our group three patients' results were also affected by use of the Advance Off-Stylet technique, which avoided significant contact with the lateral cochlear wall during insertion and controlled the insertion length (so as not to exceed 17–19 mm), in order to minimise hearing loss at low frequencies.[10,11]

Conclusions

Preservation of residual hearing is possible in cochlear implantation surgery. Recent studies have shown that residual hearing can be preserved in a good percentage of cases, if great attention is paid to minimising surgical trauma. Thus, reducing the extent of trauma to cochlear structures must be the goal of every cochlear implantation procedure. Studies on temporal bones have demonstrated that

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loss of residual hearing following implantation is the result of a combination of many variables, including the cochleostomy technique, the site and size of the cochleostomy, and the electrode design, length, diameter and mechanical characteristics.

In the present study, we achieved rates of residual hearing preservation similar to those reported in the multicentre studies of Kiefer *et al.*,[20] Fraysse *et al.*[10] and James *et al.*[11] Together with previously published literature, our experience demonstrates several critical aspects of atraumatic cochlear implantation surgery, that is: creating a cochleostomy antero-inferior to the round window niche; allowing a direct approach to the scala tympani; minimising the loss of perilymphatic fluid; and controlling the penetration depth (so as not to exceed 17–19 mm). Moreover, we found that use of the Advance Off-Stylet technique assisted preservation of residual hearing following Contour Advance electrode implantation, enabling reduced trauma to the lateral cochlear wall during electrode insertion.

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