

ORIGINAL RESEARCH

Impact of electrode insertion depth on intracochlear trauma

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OBJECTIVE: To assess the effect of cochlear implant (CI) insertion depth and surgical technique on intracochlear trauma.

STUDY DESIGN AND SETTING: Twenty-one fresh human temporal bones were implanted with CI electrodes and underwent histologic processing and evaluation. Specimens were grouped into 3 categories: 1) soft implantation technique and standard electrode; 2) soft implantation technique and flexible prototype array; 3) forceful implantations and standard electrode. Based on the grading system (1 to 4), 2 numeric values were calculated indicating the overall severity of cochlear damage (trauma indices).

RESULTS: Mean trauma index values were 13.8, 36.3, and 59.2 for group 1, 2, and 3, respectively. Differences in cochlear trauma (trauma index) were nonsignificant between specimens in groups 1 and 2 but were significant between groups 1 and 3.

CONCLUSION: This study gives evidence that intracochlear trauma increases with deep insertions. Thus, in cases where cochlear integrity might be important, limited insertions should be achieved.

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Until 1993, when Lehnhardt¹ first described the soft surgery technique for inserting intracochlear electrodes, little effort was made to protect and preserve inner ear structures. Initially, the goal of soft surgery was to ensure the presence of sufficient excitable neuronal structures for electrostimulation. A few years later, Hodges et al² described residual acoustic hearing postoperatively in about 50% of patients who underwent cochlear implantation. Although soft-surgery techniques had been already used by many surgeons at that era, preoperative, and therefore also

postoperative hearing remnants were small and did not influence overall implant performance. Only a few years later, the electric acoustic stimulation (EAS) of the auditory system was first described,³ a method that combines remaining “natural” cochlear function with electric stimulation of a cochlear implant on the same ear. During the same time, an alternative approach using a shorter electrode array was under development⁴ and both groups could show the markedly improved speech perception results in noise compared to the cochlear implant alone mode.^{3,4} Improvements were also documented for music perception.⁴

The promising results of the first EAS patients promptly created interest in hearing preservation in cochlear implant surgery. Basic research including neurophysiology and molecular biology, for example, has been focusing on detection of the exact mechanisms of hearing loss during surgery and possible solutions.^{5,6} Although a lot of progress has been made since the introduction of EAS, and further reports confirmed initial speech perception data,^{4,7} most issues in hearing preservation and subsequent EAS have remained unsolved. It is generally believed, however, that intracochlear trauma caused by insertion of the stimulation electrode, contributes significantly to the success or failure of intraoperative hearing preservation.⁸

Apart from preservation of acoustic hearing, intracochlear trauma is also likely to effect the degeneration of excitable structures in the spiral ganglion and inner ear. Animal experiments, for example, have documented the large impact of minor intracochlear trauma to the spiral ganglion cell count.⁹ These morphologic changes were also correlated with negative changes in electrophysiologic pa-

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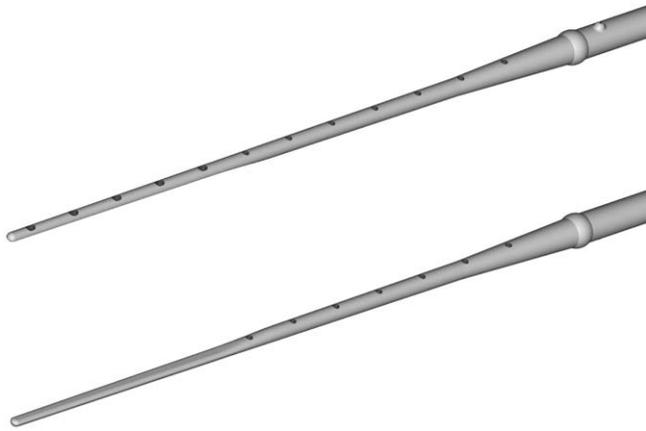


Figure 1 Three-dimensional computer rendered picture of the FLEX^{soft} electrode. Both sides of the electrode can be seen. Five most apical contacts are single. A 30% reduction of the apical diameter compared to the standard array and better apical flexibility were achieved. Length of the array and contact spacing are identical with the C40+ electrode. Picture courtesy of MED-EL, Innsbruck, Austria.

rameters over time.¹⁰ Considering that cochlear implants in children will probably provide acoustic information for their remaining life span, preservation of neural structures might be critical for long-term performance.

Another topic in cochlear implant research is the contribution of apical cochlear regions. Some authors, for instance, state that every cochlear implantation should be carried out beyond 1 full turn to stimulate apical regions.^{11,12} Considering apical cochlear morphology, however, deep implantations could potentially cause considerably more trauma than shallow insertions into the basal and early middle turns only. In a report from the early ages of cochlear implantation, Zrunek et al¹³ described that cochlear trauma was neither related to the type of the array, nor to the depth of insertion. In a recent report, Neumann et al¹⁴ have studied the effect of insertion depth on preservation of residual hearing and found better results with shallower insertions. They attributed that effect to the increased resistance encountered during limited insertions. Other authors have evaluated trauma and intracochlear electrode positions after implantation of long arrays. Insertions were stopped after resistance was felt, however, thus resulting in limited insertions in the postmortem temporal bone.

The aim of this article was to study the effect of insertion depth, electrode design, and implantation technique on intracochlear trauma and electrode positioning in a cadaver temporal bone model.

METHODS

This study was carried out in accordance with the local institutional review board (IRB).

Electrodes Evaluated

Forceful and gentle insertions were compared using a standard (C40+) and an experimental prototype electrode (FLEX^{soft}). Both arrays were manufactured by MED-EL (Innsbruck, Austria). The aim of developing the new prototype electrode, FLEX^{soft}, was to decrease cochlear trauma for deep intracochlear insertions. In the 2-component silicon (medical grade) body of both arrays (FLEX^{soft} and C40+ standard), platinum contacts are distributed over a length of 26.4 mm. Wires measure 25 μm in diameter and are made of a platinum-iridium alloy (90/10). Contacts measure 800 μm \times 500 μm and in the regular C40+ electrode, all contacts are paired, placed on opposite sides of the electrode body. In the FLEX^{soft} electrode, the 5 most apical electrode contacts are single to increase flexibility. This reduces the diameter at the tip to about 70% of the standard array. The intracochlear part of the C40+ electrode is slightly oval with diameters of 0.80 mm \times 0.78 mm at the basal end and 0.50 mm \times 0.48 mm at the tip. Both arrays have an overall length of 133.7 mm and an intracochlear part of 31.5 mm. See Figure 1 for a 3-D rendered picture of the FLEX^{soft} electrode.

Surgical Procedure

Twenty-one human temporal bones were harvested up to 24 hours postmortem and relayed to further processing. Fifteen bones were implanted using the standard C40+ electrode. In 6 bones, the prototype FLEX^{soft} carrier was used. All insertions were carried out using the regular mastoidectomy/facial recess approach by the same, experienced cochlear implant surgeons (O.A. and J.K.) under standardized conditions. The anatomy of the temporal bone was maintained, such that the surgical access was similar to that during live surgery. A caudal approach cochleostomy was selected to provide deep intrascalar insertions into the scala tympani. The bony overhang over the round window niche was removed and the round window was visualized. Subsequently, scala tympani was opened anterior and inferior of the round window membrane using a small burr (1.0 mm in diameter).

In 6 specimens implanted with the C40+ electrode (group 1), and in all bones implanted with the FLEX^{soft} array (n = 6, group 2), insertions were stopped when the

Table 1
Grading of insertion trauma

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

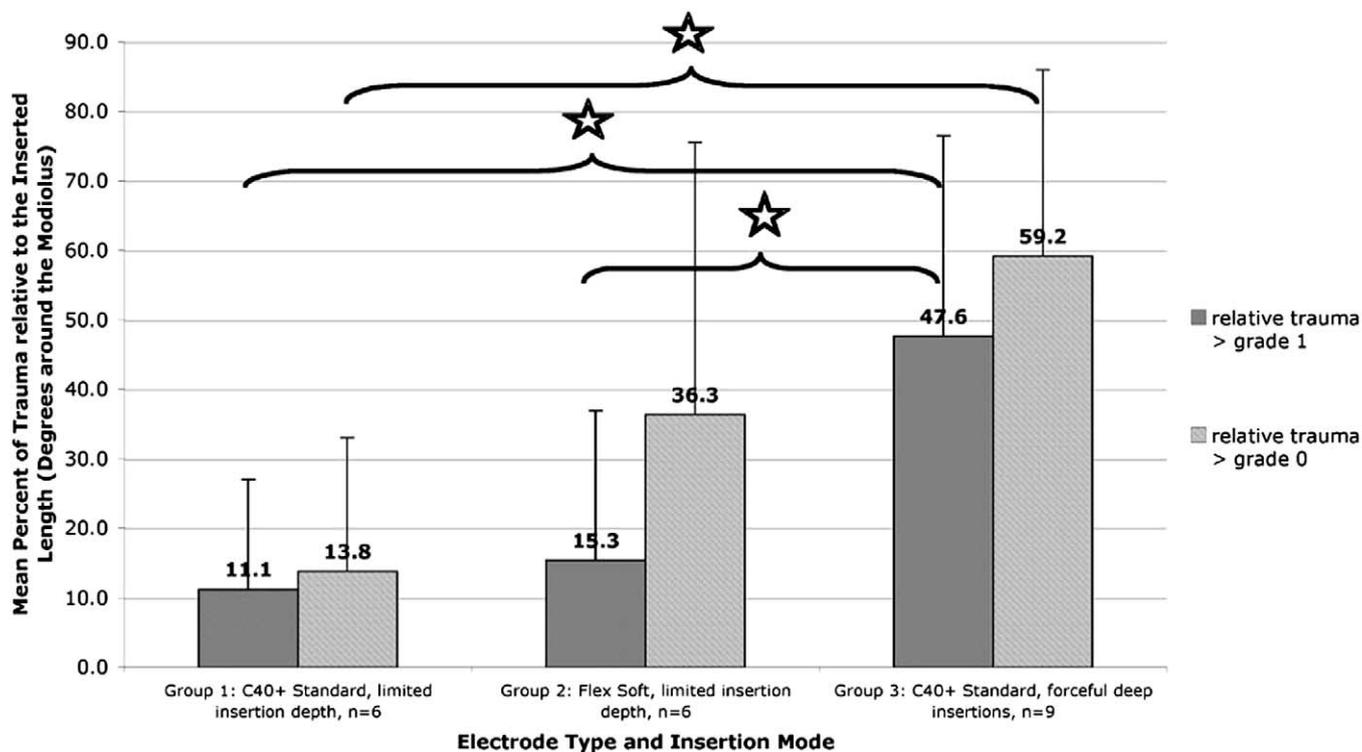


Figure 2 Graph on mean intracochlear trauma (numeric trauma indices) with different electrodes and insertion modes. Bars represent mean relative intracochlear trauma (percent of the intracochlear length of the array, that caused trauma >grade 1 or >grade 2; 50% for example means that a 360° inserted array caused trauma over 180°). Stars indicate significant differences between groups.

point of first resistance was reached. No further (forceful) insertion maneuvers were carried out in those specimens. To study the effect of deep insertions, 9 bones were implanted beyond the point of first intracochlear resistance (group 3). Thus, forceful insertion maneuvers were applied when resistance was felt and insertions were continued until basal buckling made further advancement impossible. After implantation, electrode carriers were fixed with sutures onto the remaining middle ear structures.

Specimen Preparation

All implanted specimens were prepared for histologic processing. Our routine procedure allows sectioning of undecalcified bone with the implanted array in place. Fixation was achieved using perilymphatic perfusion with buffered formalin solution. Dehydration was accomplished with an ascending series of alcohol (70% to 100% ethanol). Specimens were embedded using polymethylmethacrylate at 20°C. After embedding was completed, a conventional x-ray of the specimen to identify the position and orientation

Table 2
Main findings

Group	Bones (n)	Electrode	Insertion*	Mean insertion depths†			Trauma index‡	
				Surgical	Histologic	Radiologic	>Grade 1	>Grade 0
1	6	C40+ Standard	Soft surgery	20.3	305.0	276.7	11.1	13.8
2	6	Flex Soft	Soft surgery	25.2	540.0	505.0	15.3	36.3
3	9	C40+ Standard	Forceful	30.8	535.0	536.7	47.6	59.2

*Insertion mode: insertions were stopped at the point of first resistance in the forceless insertion mode, whereas insertions were forcefully continued in the forceful insertion mode.

†Surgical insertion depths in mm from the cochleostomy; histologic and radiologic insertion depths measured in degrees around the modiolus.

‡Trauma indices: the total length of the intracochlear part of each electrode was related to the length of the traumatic part (2 indices, trauma being either >grade 1 or >grade 0). Both indices represent percentage values of the extent of cochlear trauma relative to the insertion depth (in degrees around the modiolus).

of the electrode was carried out in collaboration with our radiology department. The radiologic insertion depth of each array was also evaluated in terms of degrees around the modiolus. Then the specimens were sectioned serially at a thickness of 100 μm . A 90° angle between the sectioning plane and the electrode orientation within the cochleostomy was chosen to allow evaluation of exact trauma location within the scala tympani. A special grinding and polishing technique developed by Plenk¹⁵ was used to enhance the quality of each slide. Specimens were stained with Giemsa.

Evaluation of Insertion Properties

All specimens were evaluated by both authors independently. Insertion properties were evaluated according to a standardized grading scheme developed by Eshraghi et al¹⁶ (Table 1). Additionally, electrode diameters were measured to exclude swelling artifacts seen rarely in past experiments. Grading of intracochlear trauma was determined for each location in the cochlea and entered in a database.

To allow for accurate comparisons, a numeric value indicating the relative length of cochlear trauma was calculated for each specimen (subsequently termed *trauma index*). In principle, the total length of the intracochlear part of each electrode was put in relation to the length of the traumatic part (2 indices, trauma being either >grade 1 or >grade 0). Thus, both indices represent percentage values of the extent of cochlear trauma relative to the insertion depth (in degrees around the modiolus). The presence of statistically significant differences in cochlear trauma and insertion depths among groups was determined using the Mann-Whitney *U* test ($P < 0.05$). Representative results were documented photographically.

Insertion Force Measurements

Insertion forces were measured in an acrylic model of the scala tympani. The model replicated the human scala tympani, was based on x-ray microscopic images of a human scala tympani, and was built with stereolithographic methods. Before insertions, the model was filled with a silicon oil to reduce friction forces. To measure forces during insertion, a high precision scale (Precisa Instrument AG, Dietikon, Switzerland) and a testing machine (Lloyd Instrument Ltd., Fareham, UK) were used.

After fixation of the electrode carrier to the load cell, the array was slowly driven into the scala tympani model at precise intervals and speed. As the electrode penetrated the model, the force generated was recorded by the scale, on which the scala tympani model was placed. The model was filled with a medical grade silicone oil to reduce the friction between the outer wall and the array. During the electrode insertion into the scala tympani, the force measurements at each insertion step were recorded from the scale. Parameters like speed of electrode progression were standardized to minimize variations. Force measurements were recorded for 14 C40+ standard and 8 FLEX^{soft} electrodes. A schematic

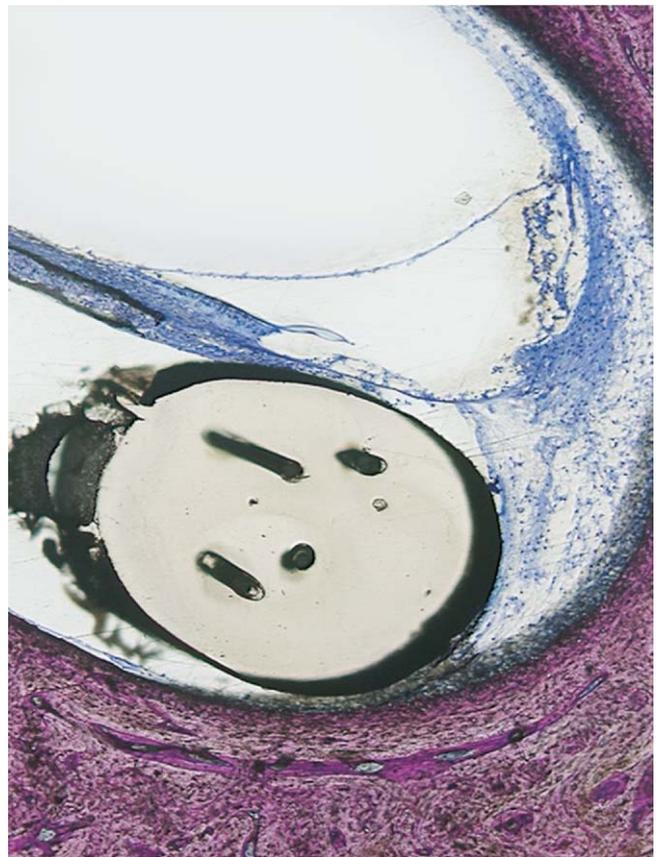


Figure 3 Specimen 1, detailed view of the basal part of the inserted C40+ Standard electrode. Soft surgical principles were applied and the electrode insertion was stopped as the first intracochlear resistance was felt during implantation. Surgical insertion depth: 20 mm, radiologic and histologic insertion depth: 270°; no cochlear trauma in the basal part as depicted in the image.

drawing of the insertion force apparatus is shown in Figure 2. Due to the size of the model, insertion depths were limited to 27 mm.

RESULTS

Utilizing the described technique for specimen preparation, electrode positions and the extent and location of intracochlear trauma could be clearly evaluated in each bone. Moreover, no swelling artifacts were seen in any specimen. According to the criteria described above, all specimens were included. X-ray images provided exact position and orientation of all electrodes within the embedded temporal bones and planes for correct sectioning could be identified. See Table 2 for a summary of results and Table 3 for a comprehensive list of all specimens.

Insertion Depths

Surgical insertion depths ranged from 16.0 mm to 31.5 mm (mean = 26.2 mm) for all 3 groups. For group 1 (C40+, no force), first resistance was reached after 16.0 mm to 24.0

Table 3
Implantation and trauma data on all 21 specimens

Number	Electrode		Insertion mode*	Insertion depth†		
	Side	Type		Surgical	Histologic	Radiologic
1	Left	C40+ Standard	Soft surgery	20	270	270
2	Left	C40+ Standard	Soft surgery	20	270	270
3	Left	C40+ Standard	Soft surgery	24	270	180
4	Right	C40+ Standard	Soft surgery	16	300	270
5	Right	C40+ Standard	Soft surgery	23	420	400
6	Left	C40+ Standard	Soft surgery	19	300	270
7	Right	Flex Soft	Soft surgery	24	360	390
8	Left	Flex Soft	Soft surgery	30	740	720
9	Right	Flex Soft	Soft surgery	30	720	630
10	Right	Flex Soft	Soft surgery	20	420	360
11	Right	Flex Soft	Soft surgery	24	600	570
12	Right	Flex Soft	Soft surgery	23	400	360
13	Right	C40+ Standard	Forceful	31.5	630	630
14	Right	C40+ Standard	Forceful	28	540	540
15	Left	C40+ Standard	Forceful	31.5	450	540
16	Left	C40+ Standard	Forceful	31.5	540	540
17	Left	C40+ Standard	Forceful	29	540	480
18	Right	C40+ Standard	Forceful	31.5	630	630
19	Left	C40+ Standard	Forceful	31.5	540	540
20	Right	C40+ Standard	Forceful	31.5	405	390
21	Left	C40+ Standard	Forceful	31.5	540	540
Min				16	270	180
Max				32	740	720
Mean				26.2	470.7	453.3
Median				28	450	480

*Insertion mode: insertions were stopped at the point of first resistance in the forceless insertion mode, whereas insertions were forcefully continued in the forceful insertion mode.

†Surgical insertion depths in mm from the cochleostomy; histologic and radiologic insertion depths measured in degrees around the modiolus.

‡Trauma Indices: the total length of the intracochlear part of each electrode was related to the length of the traumatic part (2 indices, trauma being either >grade 1 or >grade 0). Both indices represent percentage values of the extent of cochlear trauma relative to the insertion depth (in degrees around the modiolus).

mm (mean = 20.3 mm) and insertions were stopped subsequently at that point. With the FLEX^{soft} electrode (group 2), resistance was reached after 20.0 mm to 30.0 mm (mean = 25.2 mm). Specimens of group 3 (forceful C40+ insertions) were inserted from 28.0 mm to 31.5 mm (average = 30.8 mm).

Histologically measured insertion depths ranged from 270° to 750° around the modiolus (mean = 470.7°). Mean values were 305, 540, and 535° for group 1 (C40+, no force), group 2 (FLEX^{soft}), and group 3 (C40+, forceful), respectively. The mean radiologic insertion depth for all 3 groups was 453.3° (from 180° to 720°). Average group values were 276.7°, 505.0°, and 536.7° for group 1, group 2, and group 3, respectively. In general, radiologic and histologic insertion depths correlated statistically (Pearson's coefficient). Differences in insertion depths between groups 1 and 3 and between groups 1 and 2 were statistically significant ($P < 0.05$) regardless of the method of measurement (surgical, radiologic, histologic). In contrast, only differences in surgically evaluated insertion depths between groups 2 and 3 were statistically significant.

Electrode Positions and Intracochlear Trauma

All bones were primarily implanted into scala tympani. No fractures of the bony modiolar wall were observed in any specimen. However, intracochlear grade 4 trauma (fractures of the osseous spiral lamina) adjacent to the cochleostomy was observed in 6 of 21 bones. Only 1 bone of group 1 (1 of 6, 16.7%) showed grade 4-trauma. Grade 4-trauma was present in 3 bones of group 2 (3 of 6, 50%) and in 7 bones of group 3 (7 of 9, 77.8%).

Two numeric values were calculated for each specimen to quantify cochlear trauma: trauma index >grade 1 (classifying grades 2, 3, and 4 as traumatic, slight basilar membrane lifting, and grade 1 as non-traumatic) and the trauma index >grade 0 (classifying grades 1 to 4 as traumatic).

Values for the trauma index >grade 0 ranged from 0.0 to 95.2 (mean = 39.7; indicating that, on average, 39.7% of the length of the inserted electrode were traumatic; grades 1 to 4). Trauma indices >grade 1 ranged from 0.0 to 93.3 (mean = 28.0; grades 2 to 4) among all bones. Mean trauma indices >grade 0 were 13.8, 36.3, and 59.2, for group 1, 2,

Table 3
(continued)

Location and extent of trauma (°)					Trauma index‡	
Grade 0	Grade 1	Grade 2	Grade 3	Grade 4	>Grade 1	>Grade 0
30-270		0-30			11.1	11.1
70-110, 130-160, 200-270		160-200		0-70	40.7	48.1
0-270					0.0	0.0
70-300	45-70	0-45			15.0	23.3
0-420					0.0	0.0
0-300					0.0	0.0
30-360	0-30				0.0	8.3
0-30, 80-180, 220-300	30-45, 180-220, 360-700	300-360, 700-740		45-80	18.2	71.6
30-70	70-110, 170-400	110-170	400-720	0-30	56.9	94.4
0-420					0.0	0.0
30-400	400-560	560-600		0-30	11.7	38.3
0-380			380-400		5.0	5.0
0-30	30-90		90-630		85.7	95.2
30-180	180-360		360-540	0-30	38.9	72.2
0-30				30-450	93.3	93.3
90-270	270-360		360-540	0-90	50.0	66.7
45-500		500-540		0-45	15.7	15.7
0-30, 60-360		360-630		30-60	47.6	47.6
0-45, 90-360	360-450	450-540		45-90	25.0	41.7
0-270	270-360	360-405			11.1	33.3
0-180	180-210		270-540	210-270	61.1	68.7
					0.0	0.0
					93.3	95.2
					28.0	39.7
					15.7	38.3

and 3, respectively. Average values for trauma indices >grade 1 were 11.1, 15.3, and 47.6, respectively. Table 2 summarizes those findings.

Both trauma indices showed that differences between groups 1 and 3 were statistically significant ($P < 0.05$). Differences between groups 1 and 2 were nonsignificant in either index. Differences between groups 2 and 3 were statistically significant in the trauma index >grade 1, only ($P < 0.05$). Figure 2 illustrates the results for the trauma indices and indicates significant differences. Figures 3 to 5 show exemplary histologic images.

Insertion Forces

Force measurement data for the C40+ standard ($n = 14$) and the FLEX^{soft} ($n = 8$) are shown in Figure 6. Insertion forces for both electrodes increased dramatically beyond insertion depths of about 18 mm to 20 mm. At 27 mm intrascalar insertion depth, the average force of insertion for the C40+ standard array was 75.9 mN compared to a mean value of 53.5 mN for the FLEX^{soft} carrier, equaling a reduction of average forces by 29.5%.

DISCUSSION

This study gives evidence that the likelihood of intracochlear damage increases with deep intracochlear electrode

insertions in a human cadaver temporal bone model. This finding was reinforced by the findings of our force measurement experiment. With the antimodiolar, free fitting standard MED-EL cochlear implant electrode, forceful insertions caused statistically significantly more trauma than insertions with the same electrode where soft surgical principles were applied. Modification of the tip region of the electrode in a new prototype resulted in significantly deeper insertions with soft surgery than with the standard electrode carrier using a soft surgery technique. Clinically, those principles include avoidance of perilymphatic fluid loss, drilling of a small cochleostomy, and gentle handling of the electrode during the insertion process. Due to the postmortem nature of the temporal bones, soft surgical principles used herein consisted of a small cochleostomy (about 1.0 mm in diameter), use of a lubricant, and smooth and non-forceful electrode insertions.

These insertion depths were comparable to forceful insertions with the standard array (radiologic and histologic measurements), but showed significantly lesser trauma when considering slight lifting of the basilar membrane (grade 1) as not traumatic (trauma index >grade 1). Most likely, the modified tip influenced the perception of intracochlear resistance, which in turn resulted in extensively deep insertions. Subsequently, those specimens showed greater trauma and deeper insertions than smooth insertions with the standard electrode.



Figure 4 Panoramic view of specimen 11, FLEX^{soft} electrode. Soft surgical principles were applied during electrode insertion. Scala tympani insertion into basal and middle cochlear turns. Image shows grade-4 basal cochlear trauma (lower right) due to the cochleostomy, atraumatic electrode placement in the remaining basal turn, and basilar membrane rupture (grade 2-trauma) in the middle cochlear turn. Bony modiolar wall and osseous spiral lamina remain intact. Surgical insertion depth: 24 mm.

Translating the results of this human temporal bone study into real cochlear implantations with hearing preservation seems quite difficult. The factors contributing to the outcome of hearing preservation during cochlear implantation and their interaction are still unknown. The importance of intracochlear trauma might be little compared to other factors. Also, the grading system¹⁶ used herein is quite arbitrary and thus the negative functional consequences might not be in accordance to the ascending numeric trauma classification of the grading system. Because the exact mechanisms of hearing preservation remain unidentified, however, all possible contributors have to be considered, and one of them being intracochlear trauma.

Besides the characteristics of the electrode itself (length, stiffness, cross-sectional diameter), trauma to intracochlear structures can be attributed to several factors including the forces that are exerted on the tissue and the dimensions of the fluid space. If force is exceeding the resistance (eg, of the basilar membrane), damage will be observed. The same holds true if the dimensions are too small to accommodate the electrode carrier. Any forceful attempt to advance the electrode further into the cochlea will result in intracochlear trauma.

Another factor potentially influencing residual hearing is the position of the electrode carrier with respect to the oscillating structures of the inner ear. The trauma classification scheme used herein describes a slight displacement of the basilar membrane as minor trauma. A recent experiment,¹⁷ however, showed that mechanical impairments of basilar membrane oscillations (as caused through a grade 1 trauma) might lead to hearing deterioration and frequency shifts.

Extensive damage observed in deep insertions could be related to the dimensions of the cochlea in the middle turn and to the fact that greater forces are usually necessary to place an array in the middle turn. Because deeper insertions are usually possible during live surgery,¹⁸ possibly because frictional resistance is reduced less than in the post mortem temporal bone, the limitation of cochlear dimensions in the middle and apical region of the cochlea could result in increased cochlear trauma in real implantations.

One of the major issues in reduction of intracochlear trauma seems that the spiral ligament in the lateral scala tympani wall directs the electrode toward the basilar membrane. Increased forces during insertion tend to exert forces onto the undersurface of the basilar membrane. Pre-curved electrodes such as the Contour Advance array (Cochlear Corporation, Melbourne, Australia) might solve this problem by avoiding the lateral cochlear wall.¹⁹ A stylet straightens the pre-curved shape of the electrode before insertion. First, the electrode and its stylet are inserted together and from a certain insertion depth on, the array is advanced off its stylet, returning it to its pre-curved shape. This electrode does not strike the lateral wall of the cochlea during insertion and a perimodiolar electrode position is maintained. Insertion depths exceeding 1 full cochlear turn were not achieved (with this or other perimodiolar electrode designs),^{16,19} yet insertions beyond 1 full turn are necessary for apical cochlear stimulation.

Previous reports suggested that a distance of 20 mm from the round window corresponds to frequencies of about 1000 Hz.¹² These insertion depths are believed to be sufficient when combined electric acoustic hearing (EAS) is targeted.³ In contrast, some authors state that deep insertions for deaf candidates should exceed the 1000 Hz frequency region to provide essential speech information.^{11,18} In an acute experiment,



Figure 5 Panoramic view of specimen 16 with a C40+ Standard electrode. Forceful insertion maneuvers have been applied. A full 31.5 mm intracochlear insertion has been achieved. Grade-4 cochlear trauma (fracture of the osseous spiral lamina) was observed in the most basal portions. Slight lifting of the basilar membrane in the middle turn, and rupture of the basilar membrane and dislocation of the electrode into scala vestibuli beyond 360°.

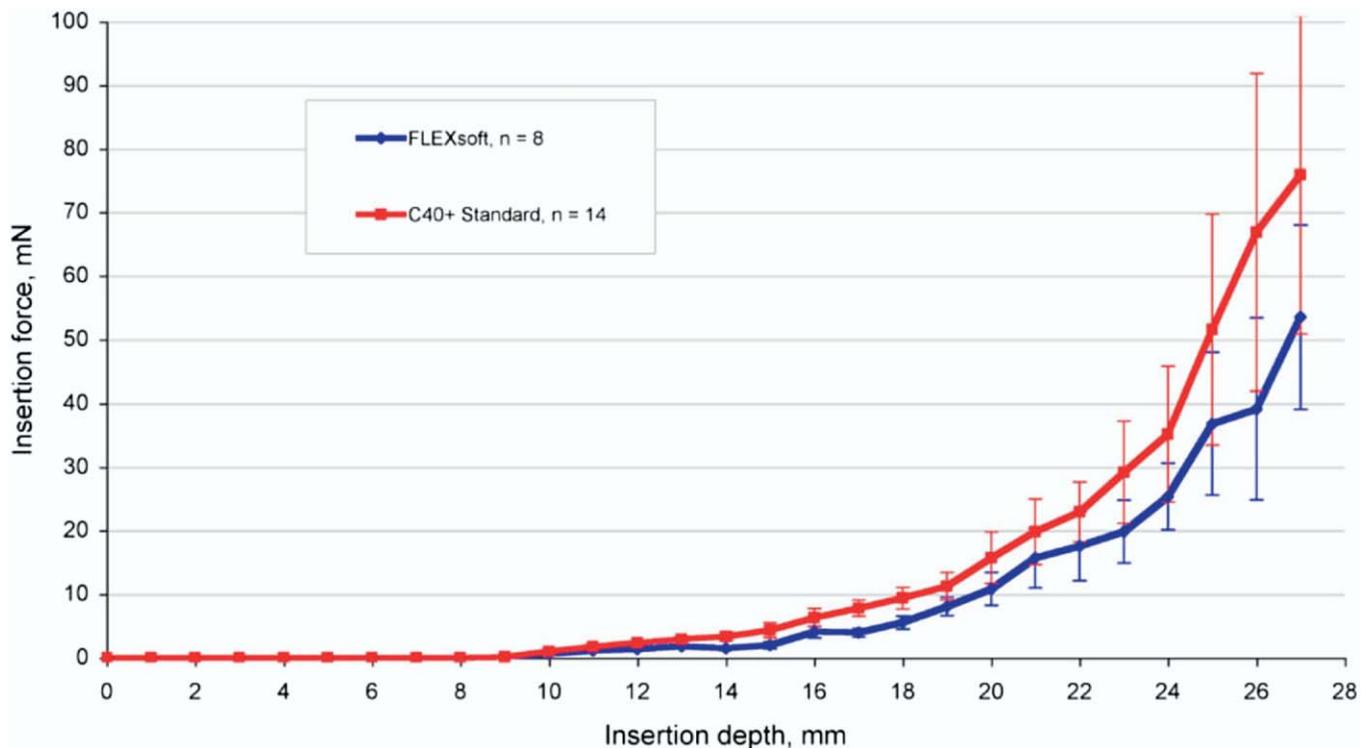


Figure 6 Mean force measurement data. The average force necessary to advance the electrode into the acrylic temporal bone model was reduced by almost 30% with the FLEX^{soft} electrode compared to the Standard C40+ array. Insertion forces for both electrodes increased dramatically beyond an insertion depth of 18 mm to 20 mm.

Hochmair et al¹¹ restricted stimulation to the apical, middle, and basal regions of the cochlea via deactivation of corresponding electrode contacts in fully inserted patients (>30 mm). The results showed that apical regions of the array carried significant information for speech discrimination in quiet and in noise. In an earlier paper, sentence scores were shown to be significantly higher with stimulation of apical cochlear regions compared to stimulation of the basal regions only.²⁰ From other experiments it is clear that a tonotopic match between electrode and cochlear frequency is critical for good speech recognition. Fu and Shannon²¹ noted that speech perception scores decreased dramatically as the tonotopic location of either carrier bands or analysis bands was shifted relative to each other by >3 mm. In an acoustic simulation of a 5-channel cochlear implant,²² results indicated that simulated insertion depth had a significant effect on speech perception performance. In that case, performance with a 25 mm simulated insertion depth was the same as normal, whereas insertion depths of <23 mm led to decreasing perception scores. Most of these experiments were acute ones, however, and did not account for chronic central adaptation processes. The benefit of deep intracochlear electrode placement remains speculative.

CONCLUSION

This study suggests the importance of limited electrode insertions as one factor for the prevention of intracochlear trauma.

The use of smooth electrode insertions as part of the soft surgical principles resulted in shallower insertion depths, but significantly less intracochlear trauma when compared to forceful insertion maneuvers. Modifications of the electrode tip region by means of increasing electrode tip flexibility lead to deeper insertions and less trauma. This might be due to reduced friction forces and less electrode volume. The increased flexibility might also impair the surgeon's perception of intracochlear resistance, however, and tempt him to further advance the electrode and cause some additional trauma. Translating these temporal bone findings into live cochlear implantations remains problematic and the significance of avoiding intracochlear trauma for hearing preservation remains speculative.

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