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Selection of the appropriate cochlear electrode array using a specifically developed research software application

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Abstract

Objective. To evaluate the usefulness and reliability of a research software application for the estimation of an individual's cochlear duct length as a basis for electrode selection.

Methods. In this prospective cohort study, 21 consecutive patients (23 ears) implanted with a cochlear electrode were investigated. The study comprised 19 children (2 bilateral) and 2 adults.

Results. The measured 'A' distances (the largest distance from the round window to the contralateral wall) corresponded to cochlear duct lengths of 28.5–36.4 mm. The mean cochlear duct length was 34.05 ± 1.72 mm (33.60 ± 2.27 mm in females and 34.35 ± 1.27 mm in males). Full insertion was achieved in all but two cases. No misplaced electrode array or electrode fold-over was detected. In all but three ears, the electrode was chosen based on the research software application's indication.

Conclusion. The results show a good correlation between the pre-operatively predicted insertion depths using the software application and those post-operatively measured using X-ray. The insertion length predicted by the software was always longer than that measured via X-ray.

Introduction

The level of hearing rehabilitation of cochlear implant recipients has improved greatly since implants were first introduced in the early 1970s. Since then, continuous research has been directed towards further improvements and developments. These developments include: advanced signal processing, higher stimulation rates, greater numbers of channels and more efficient electrode arrays that are less likely to produce insertion damage.

The size of the human cochlea has a wide variability, with lengths of 25–45 mm.[1] There are a range of different lengths of electrode available for implantation. Extension of the electrodes into the apical region provides a higher percentage of cochlear coverage. This results in better initial pitch matching, which positively affects patients' performance.[2] As the insertion of the electrode is a blind manoeuvre, there is large variability in intracochlear electrode array position. It has been hypothesised that changes in electrode position may have a significant impact on speech recognition.[3]

At present, electrode bandwidths are assigned arbitrarily, taking into account the Greenwood function. However, there is reason to believe that performance would improve if bandwidth assignment was based on the average characteristic frequency for the estimated insertion depth. Knowing the position of the electrodes inside the cochlea might help us improve performance because of the tonotopicity of the human cochlea.[3]

Large variations found in human cochlear lengths imply that significant differences may exist in intracochlear frequency distributions.[4] Hence, it may be useful to have reliable measurements of the intracochlear position of the array.[3] There are four methods to estimate the intracochlear position: one is based on the surgeon's report and the other three are based on imaging.[5,6] The type and range of intracochlear array deformations may only be detected by post-operative imaging.

There is also a debate on how deep an electrode array should be inserted to ensure the balance between best performance and the potential for induced intracochlear trauma with its unpredictable long-term effects. A user-friendly, easy-to-use tool would be valuable to estimate pre-operatively the appropriate electrode length, especially when aiming for complete cochlear coverage. Choosing the right length will prevent too-deep insertions, which may cause major intracochlear damage or enable electrode contacts outside the cochlea. This study aimed to evaluate the usefulness and reliability of the cochlear duct length software CDL Application, version 4.6 (Med-El, Innsbruck, Austria) regarding the selection of the appropriate type of electrode to be implanted. It also aimed to compare the insertion depth results with post-operative X-rays of the cochlea and the surgeon's intra-operative notes.

Main Article

Dr E H Stefanescu takes responsibility for the integrity of the content of the paper

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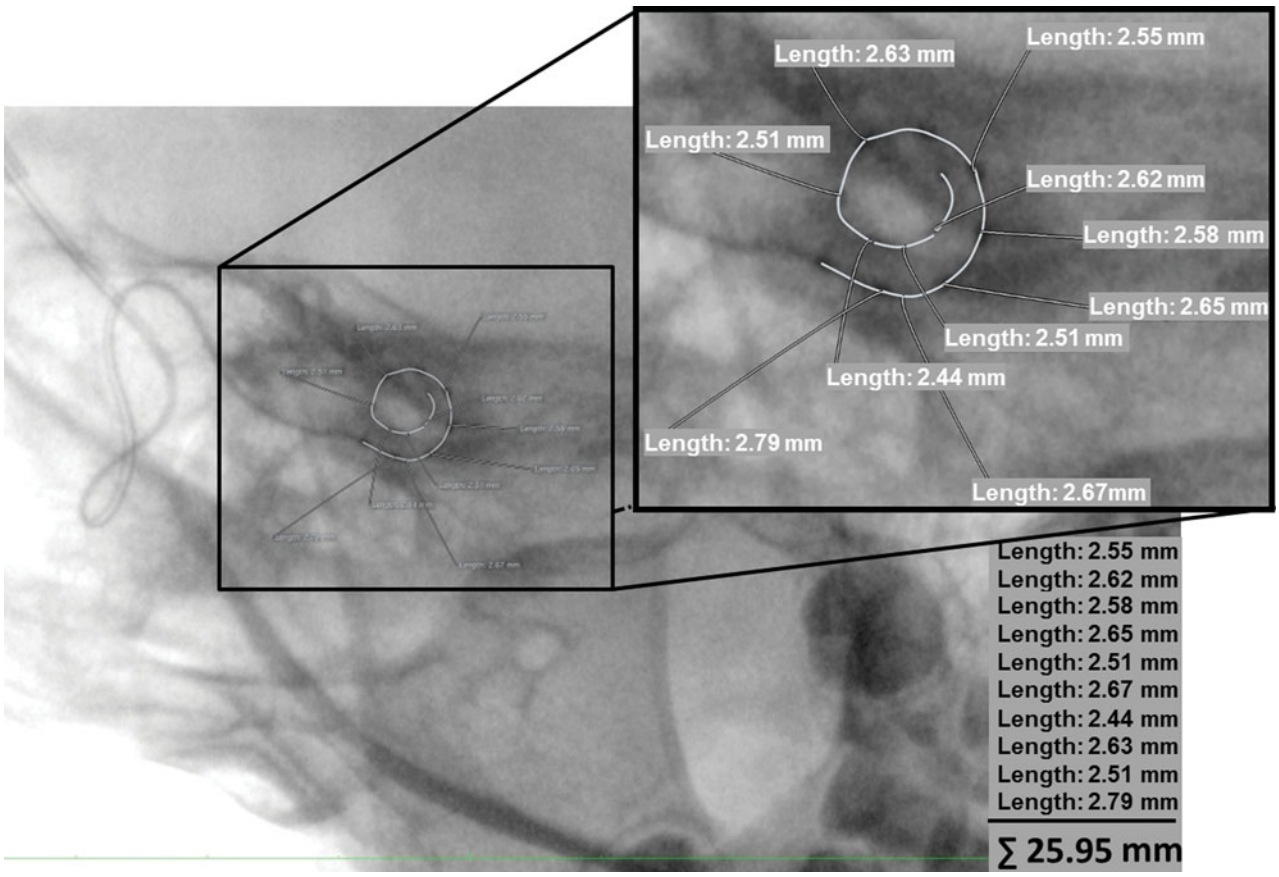


Fig. 1. Calculating the distance between electrode contacts on X-ray.

Materials and methods

We used to perform the post-operative X-ray of Stenver's view in cochlear implant recipients. Since 2014, we have been using the cochlear view to check the position of the electrode array. This latter view better shows the entire length of the intracochlear electrode array in one image, and it is a simple low-cost method with low radiation.[7]

We used the cochlear duct length software in 21 patients (23 ears; 19 children (2 bilateral) and 2 adults) who had all been implanted with Med-El devices. All but three patients were prelingually deafened (two adults and one child). Using the software, we calculated the cochlear duct length (2.5 turn length) and the length of the first two turns of the cochlea (2 turn length) for the ears that were to be implanted. These measurements were carried out to aid selection of the appropriate type of Med-El electrode array. In our calculations, we measured the distance 'A' (the linear measurement from the round window to the farthest point on the opposite wall of the cochlea, as described by Escude *et al.*[8]) on a coronal section of a high-resolution computed tomography (CT) scan of the temporal bone.

In the first five cases, we routinely used the standard electrode array (31.5 mm), even if the software suggested a shorter electrode, as they were the only electrodes available. After we had started using soft electrode arrays, we always followed the software recommendations regarding the length of electrode arrays, except in two private patients (one bilateral and one unilateral) who demanded Flexsoft™ electrode arrays against our advice. We always chose the longer electrode when the software suggested two options.

In order to calculate the insertion depth of the most apical electrode on an X-ray of the cochlea, we used the following formula (measured intra-operatively by the surgeon): Σ of all measured distances between centres of visible electrode contacts + inserted part of the electrode array, from the last contact up to the silicon ring or marker, or up to the point where the electrode array exits the cochlea (Figure 1). The 'A' distance was measured from the CT scans, and was defined as the largest distance from the round window to the contralateral wall (Figure 2).

Results

Using the software, we found gender-related differences regarding the length of the cochlea. The 'A' distance (the largest distance from the round window to the contralateral wall) measured on CT scans varied from 7.8 mm to 9.7 mm, with a mean value (± standard deviation (SD)) of 9.14 ± 0.415 mm (9.03 ± 0.55 mm in females and 9.21 ± 0.30 mm in males) (Figure 2). The measured 'A' distances corresponded to cochlear duct lengths of 28.5–36.4 mm. The mean cochlear duct length (± SD) was 34.05 ± 1.72 mm (33.60 ± 2.27 mm in females and 34.35 ± 1.27 mm in males) (Table I). The mean variation range of the 'A' distances was 7.9 mm, transferring into a 21 per cent deviation rate from the maximum cochlear duct length. According to the software, the cochlear coverage was over 80 per cent in all cases (Figure 3).

In all but three ears we followed the recommendations made by the software for selecting the electrode array. When we retrospectively assessed the five ears implanted before using the software (all standard electrodes), we found that in four cases we should have used a shorter electrode. However, we had only one incomplete insertion (1 mm distance to the marker), but no electrode contacts remained outside the

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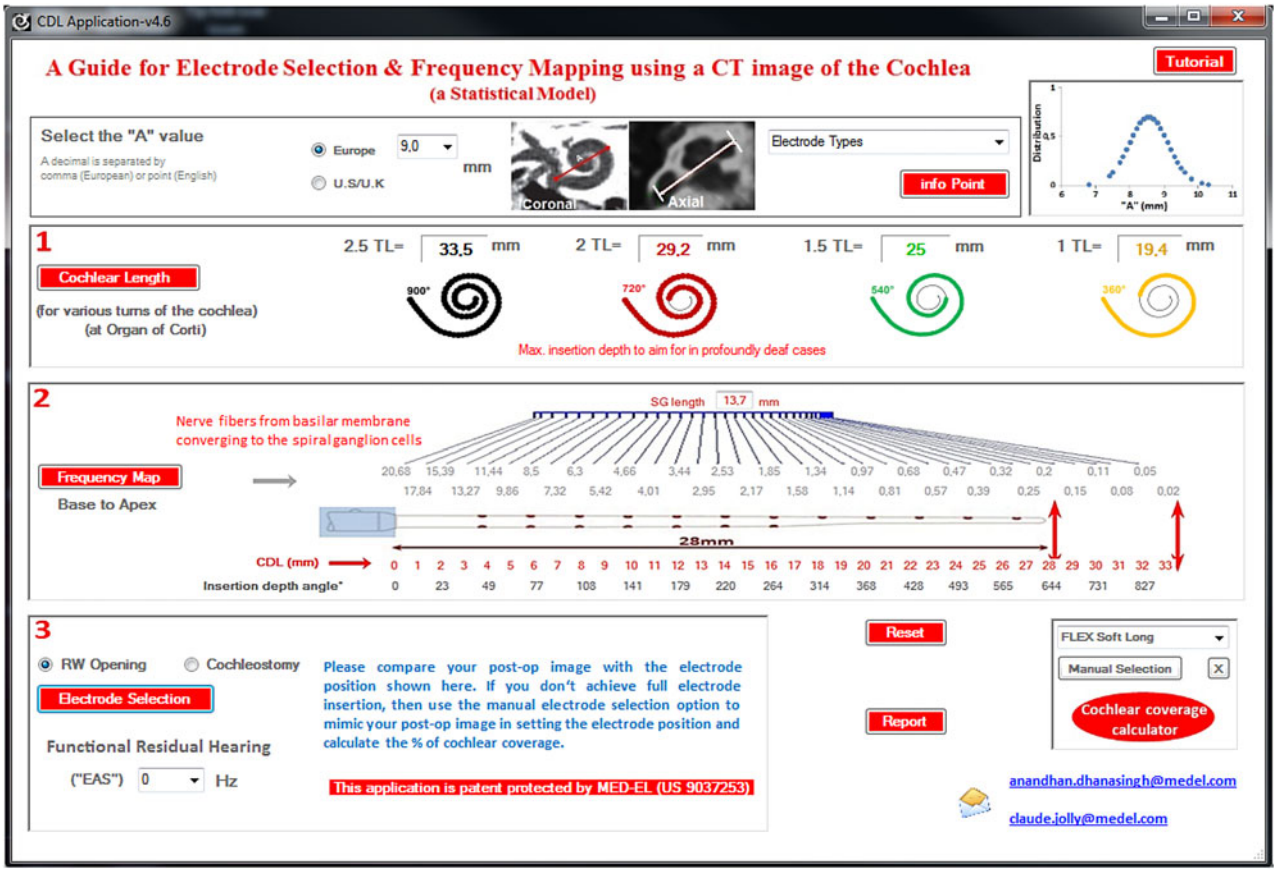


Fig. 2. Choosing the electrode array using the cochlear duct length software CDL Application, version 4.6.

cochlea. One might say the software is overcautious, but we think it is helpful in preventing intracochlear trauma when aiming for complete cochlear coverage.

A comparison between the methods of insertion depth evaluation is presented in Table II. The insertion length represents the actual inserted part of the electrode, without taking the insertion route into consideration. The insertion length is constant (30.5 mm for the long electrode and 27.0 mm for the shorter electrode, according to the software), but the insertion depth and the insertion angle are dependent on the type of insertion (cochleostomy or round window insertion techniques). The difference between the point of entry in cochleostomy and round window insertion techniques was considered 2.0 mm, as we always performed the cochleostomy anterior and inferior to the round window, and we did not use the extended round window approach.

The differences between the insertion depth and insertion length predicted by software and calculated on the X-ray were not significant. However, the difference between predicted and calculated insertion depth and insertion length is almost twice as much when comparing the Flexsoft to Flex28™. This is probably a result of the variable geometry of the cochlear apex. The deeper the insertion, the more variable and unpredictable the position of the electrode array.

Discussion

Knowing where the electrode contacts provide stimulation along the cochlea may help us predict the characteristic frequencies of neurons closest to individual electrode contacts.[3,7] Providing a closer relationship between electric stimulation and frequency placement may result in better speech understanding and music appreciation.[9] Marsh *et al.* found a significantly higher correlation between individual sentence recognition test scores and electrode array position when the insertion depth was estimated based on modified Stenver's view plain X-ray films ($r = 0.59$, $p < 0.06$) than when estimated based on surgical observations ($r = 0.33$, $p < 0.15$).[10] However, other studies have shown that even if sound generated by the electrode array may stimulate a different place and different frequencies, the brain may learn to adapt to this misplaced stimulation.[11]

Normal cochleae vary by 2.0 mm in distance A. By calculation, this leads to a 5.0 mm variation in the length of the lateral wall from 0 to 360°. This accounts for the large variation seen in insertion depth angles, as observed in post-operative radiograms.[8]

- Novel research software to quickly estimate cochlear duct length is proposed
- The method relies on cochlear basal turn diameter measurements from temporal bone computed tomography (CT) scans
- The software predicts cochlear implant electrode insertion depth based on the CT scans
- In the 21 patients analysed, the predicted results were compared to post-operative X-ray measurements
- Reliable correlation between the predicted and measured insertion depths was found

The advantages of deep insertion are still being debated. It is true that deep insertion increases the risk of intracochlear trauma, but the stimulation of the apical part of the cochlea provides spectral information to the cochlear implant user,

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TABLE I SELECTION OF ELECTRODE ARRAY USING CDL APPLICATION 4.6, AND COMPARISON TO EFFECTIVE INSERTION DEPTH AND CLINICAL DATA

Year	Pt no.	Age (y)	Sex	'A' size (mm)*	CDL (mm)	2 turn length (mm)†	Cochlear coverage (%)	Insertion depth / software prediction (mm)/ effective insertion (mm)	Proposed electrode	Electrode used
2013	1	3	F	9.1	33.9	29.6	92.9	Full/30.5/29.8	Flex28	Standard
	2	45	M	9.2	34.3	29.9	91.8	Full/30.5/30.0	Flex28/Flexsoft	Standard
	3	4	F	8.9	33.0	28.9	92.4	30.5 mm/29.5/28.8	Flex28	Standard
	4‡	6	F	9.1	33.9	29.6	92.9	Full/32.5/31.3**	Flex28	Standard
	5	10	F	9.1	33.9	29.6	92.9	Full/32.5/31.4**	Flex28	Standard
2014	6	35	F	9.5	35.5	31.0	85.9	29 mm/29/28.7**	Flex28/Flexsoft	Flexsoft
	7	4	F	9.6	36.0	31.4	87.5	Full/30.5/28.9	Flex28/Flexsoft	Flexsoft
	8	4	M	9.4	35.1	30.7	89.7	Full/32.5/30.3**	Flex28/Flexsoft	Flexsoft
	9	5	M	9.6	36.0	31.4	87.5	Full/30.5/29.3	Flex28/Flexsoft	Flexsoft
	10	1	M	9.4	35.1	30.7	89.7	Full/30.5/28.8	Flex28/Flexsoft	Flexsoft
	11	4	F	7.8	28.5	24.8	84.2	Full/23/22.4	Flex24/Flex28	Medium
	12	1	M	8.6	31.8	27.8	88.1	Full/27/25.7	Flex28	Flex28
	13	2	M	8.9	33.0	28.9	99.1	Full/30.5/28.4	Flex28	Flexsoft
	14 – L	1	M	9.4	35.1	30.7	89.7	Full/30.5/29.0	Flex28/Flexsoft	Flexsoft
	14 – R	1	M	9.4	35.1	30.7	89.7	Full/30.5/28.9	Flex28/Flexsoft	Flexsoft
	15 – L	2	M	9.0	33.5	29.2	94	Full/30.5/29.1	Flex28	Flexsoft
	15 – R	2	M	9.1	33.9	29.6	92.9	Full/30.5/29.2	Flex28	Flexsoft
2015	16	2	M	8.9	33.0	28.9	84.8	Full/29/28.5**	Flex28	Flex28
	17	4	F	8.7	32.2	28.1	87	Full/27/26.4	Flex28	Flex28
	18	2	M	9.0	33.5	29.2	83.6	Full/27/26.3	Flex28	Flex28
	19‡	2	F	9.5	35.5	31.0	88.7	Full/30.5/28.9	Flex28/Flexsoft	Flexsoft
	20‡	5	M	9.7	36.4	31.8	86.5	Full/30.5/29.2	Flex28/Flexsoft	Flexsoft
	21	2	M	9.3	34.7	30.3	80.7	Full/27/26.1	Flex28	Flex28

*'A' size represents the largest distance from the round window to the contralateral wall. †Refers to the length of the first two turns of the cochlea ‡Second implant. **Patients underwent a cochleostomy insertion technique (the remaining patients underwent round window insertion). Pt no. = patient number; y = years; CDL = cochlear duct length; F = female; M = male; L = left; R = right

improving word recognition, particularly in noise. Additionally, the stimulation may result in an overall lower-pitched sound, resulting in a more natural sound quality.[12] Moreover, studies have demonstrated that the spiral ganglion cell bodies do not extend beyond the second turn of the cochlea.[13,14] The geometry of the apical turn is also highly variable, and this will influence the position of the electrode array. Should we therefore stimulate the apical turn? In order to decrease the likelihood of trauma to the apical region, Wright and Roland consider insertion of the electrode for 720 degrees to be the best compromise between complete cochlear coverage and minimal intracochlear trauma.[15]

Relatively few studies have investigated whether electrode insertion depth influences speech reception, and the results are variable. Blamey *et al.* did not find a significant correlation between sentence reception on the Central Institute for the Deaf test and insertion depths in the 64 participants studied.[16] Hodges *et al.* reported that insertion depths ranging from 17 to 25 mm did not correlate with Northwestern University Auditory Test Number Six ('NU-6') word recognition scores.[17] However, Skinner *et al.* demonstrated a significant correlation between Northwestern University Auditory Test Number Six word scores and insertion depth as a percentage of total cochlear length.[6] Finley *et al.*, using high-resolution CT images to determine electrode position, reported that increases in insertion depth were significantly related to higher numbers of electrode contacts being located in the scala vestibuli, which were significantly correlated with reduced consonant–vowel nucleus–consonant word scores.[18]

Cochlear implant recipients who have higher numbers of electrode contacts residing in the scala tympani (usually corresponding to less insertion trauma) seem to obtain higher scores on open-set word recognition testing.[6,19] This is because the likelihood of cross-turn stimulation is increased when an electrode contact lies in the scala vestibuli rather than the scala tympani.[18] However, it seems that implant recipients recognise speech cues through different stimulations provided by multiple electrode contacts, even if the signal frequency mapping does not necessarily match the probable characteristic frequencies of the electrode contact involved.[6]

Very rarely, there was no correlation between the predicted and the actual electrode length. This might be because the electrode had been bent or twisted inside the cochlea, and this will affect the actual insertion depth. Moreover, deeply inserted electrode arrays may leave the scala tympani and enter the scala vestibuli, modifying the insertion depth. The thinner and softer the electrode arrays, the greater chances of staying in the scala tympani and having a deep insertion. The main source of error in insertion depth estimates from surgical observations is the presumption that all inserted electrode arrays are evenly distributed throughout the cochlear canal.

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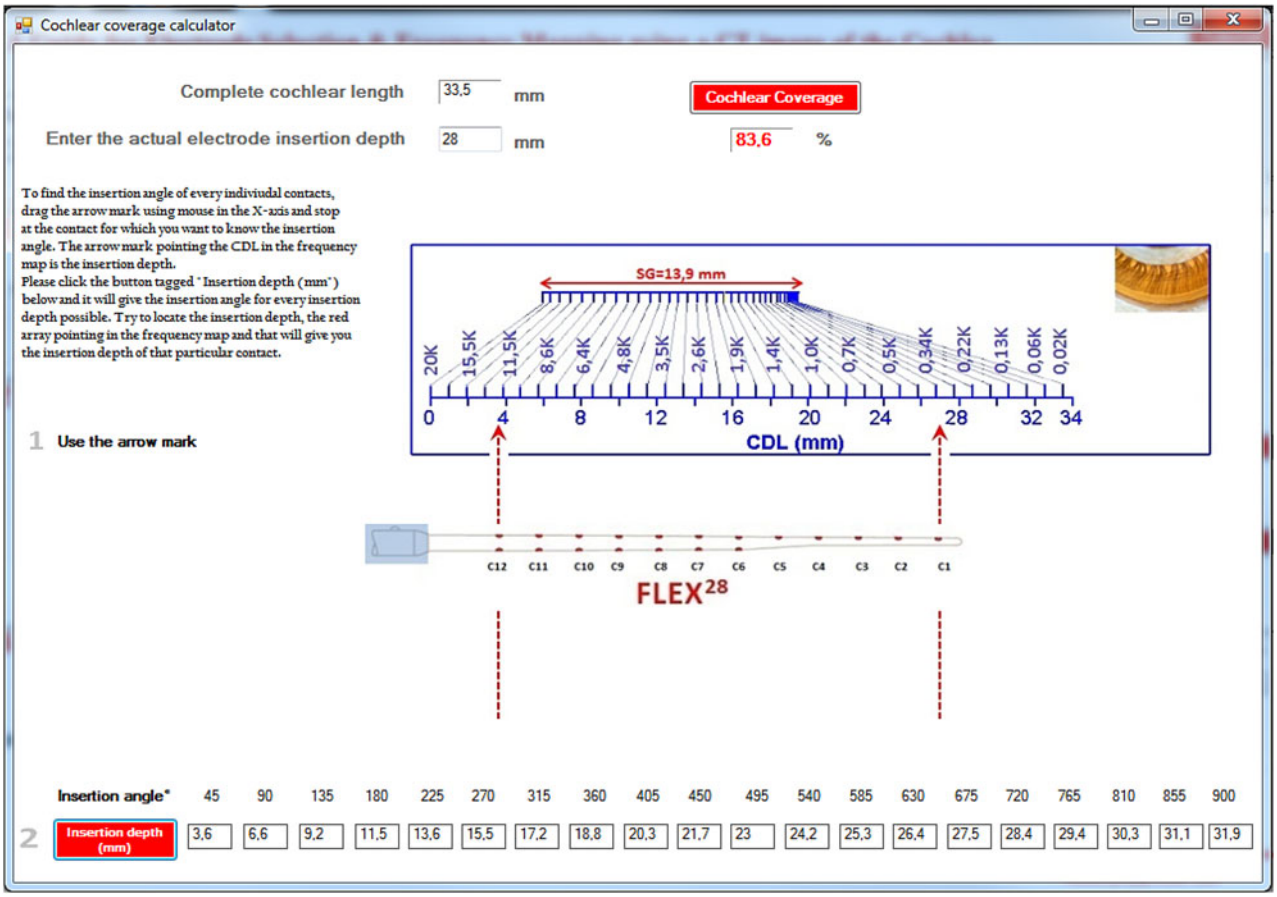


Fig. 3. Cochlear coverage estimation using the cochlear duct length software CDL Application, version 4.6.

TABLE II COMPARISON OF INSERTION DEPTH

Electrode type	Number of electrodes used	Incomplete insertion (*n* (distance from marker))	Mean insertion depth (mean insertion length); mm)		Insertion type (*n*)
			Software prediction	Effective insertion	
Flex28	5	–	27.4 (27)	26.6 (26.2)	1 Co, 4 RW
Standard & Flexsoft	5 & 12; 17 in total	1 (1 mm) & 1 (2.5 mm)	30.7 (30.5)	29.4 (28.9)	2 Co, 3 RW; & 2 Co, 10 RW
Medium	1	–	23	22.4	RW

Co = cochleostomy insertion technique; RW = round window insertion technique

Conclusion

The results suggest a good correlation between insertion depths predicted pre-operatively using the software and insertion depths calculated post-operatively using X-rays of the cochlea.

The insertion depths either calculated using the software or using post-operative X-rays are shorter than insertion depths calculated based on the surgeon's notes.

A user-friendly software that determines the optimal length of the electrode to be implanted and which reliably predicts the position of the contacts of the electrode array inside the cochlea can be of tremendous benefit for the patient, as well as for the surgeon.

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Competing interests. None declared

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