Influence of the Operating Technique of Cochlea Implantation in the Intracochlear Electrode Position Controlled by Cone-Beam CT

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Abstract

Objective: The aim of the study was to evaluate the feasibility of cone-beam computed tomography for postoperative quality control after the cochlear implantation of implant by Cochlear© and the influence of operating technique on the intracochlear positioning of the electrode.

Study design: Retrospective.

Patients and methods: A total of 102 cochlear implants (Cochlear©, Sydney, Australia) were evaluated using cone-beam computed tomography to determine the intracochlear position. The potential differentiation between the tympanic and vestibular scale was analyzed. Coherence between the cochleostomy site and the postoperative results was evaluated after analyzing the operation reports.

Results: It was possible to determine 94/102 electrodes (92%) relative to their exact intracochlear localization with a differentiation between the scales. Of these electrode arrays, 68% (64/94) were located in the tympanic scale, 28% (28/94) were located in the vestibular scale and 4% (4/94) showed a dislocation from one scale to another. Analysis of the operation reports showed an increased occurrence of tympanic scale insertions for a round window insertion compared to classic cochleostomy (75% vs. 57%). Differences between the different location of insertion were highly significant (p<0.001).

Conclusion: Cone-beam computed tomography is a proper imaging procedure for the postoperative evaluation of cochlear implant positioning in the basal cochlea turn. High resolution combined with minimized metal artifacts and a suitable post-processing procedure showed the exact location of the implant in the exact scale. Consequently, cone-beam computed tomography is an excellent instrument for clinical quality control after cochlea implantation. Further developments in soft tissue imaging for improvements in the evaluation of intracochlear trauma are desirable for the future. With the objective of hearing preservation implantation, safer cochlea implantation in the tympanic scale can be realized via a round window insertion.

Keywords: Cochlear implant electrode position; Digital Volume Tomography (DVT); Cochleostomy site; Cone-Beam Computed Tomography (CBCT); Cochlear implantation

Introduction

Cochlea implant surgery is a well established and accepted procedure for reconstituting congenital or acquired deafness. Over the past few years the indications for cochlear implantation have been expanded and now include patients with residual hearing and children [1]. In order to improve the postoperative outcome, cochlear implant insertion into the tympanic scale with minimal intracochlear trauma is aspired [2]. Thus, a postoperative radiological evaluation of the exact intracochlear implant positioning would be helpful for determining the quality of surgery. Furthermore, detailed postoperative imaging of the position of the electrode is desired in order to be able to analyze the techniques of individual surgeons.

Cone-Beam Computed Tomography (CBCT), also called Digital Volume Tomography (DVT), delivers a small radiation dose with a high resolution, and a relatively low equipment purchase price [3]. Diagnostic options of CBCT in imaging the anterior and lateral skull base could be shown before [4-8]. The problems encountered in evaluating cochlea electrodes in the middle and apical turns of the cochlea could also be shown by CBCT [9]. Therefore, in this study, we concentrated on implants by Cochlear© due to their short electrode design. Previous studies showed a high rate of vestibular scale insertions and dislocations from the tympanic to the vestibular scale [2,10]. Insertion into the tympanic scale is highly influenced by a precise and adequate choice of the cochleostomy. The objectives of this study were first to evaluate the exact postoperative intracochlear placement of the electrode by using CBCT and, second, to analyze the correlations between the type of cochleostomy performed and the postoperative intracochlear position of the implant.

Patients and Methods

A total of 82 patients with 102 implanted ears (age range: 5-88 years old) were analyzed from January 2004 to May 2011. Only patients who had implants by Cochlear© (Sydney, Australia) were included. Eight years of five patients had to be excluded due to missing raw data or insufficient image quality. In summary, 94 ears of 77 patients were included for further investigation: 56 ears of 44 female patients and 38 ears of 33 male patients. The mean age was 47.4 years old (females: 48.6 years; males: 45.6 years). The inclusion criteria included flawless quality of the raw data. Small children under the age of 5 years old did not receive a postoperative CBCT because of expected non-compliance and...
the associated impracticality of the examination, which required sitting quietly for about 17 seconds.

For CBCT imaging the patient must sit in an upright position with the head in a fixed position. The Region of Interest (ROI) is marked by target light beams that can be arbitrarily positioned. An emitter-detector unit rotates around the patient’s head and about 580 single slices of a section width down to 0.08 mm are taken. The cylindrical shape of view is 6 cm in both height and diameter. The 580 single slices are calculated to the aforementioned volume and the reconstruction of this volume is processed by a personal computer. The tube voltage was chosen depending on age and bone structure and varied between 80 and 90 kV, and the tube current varied between 4 and 8 mA. The ROI was calculated using special software (Idixel, Morita, Kyoto, Japan) and reconstructed in three plains: coronal, axial and sagittal.

Uncurling of the cochlea in one plane based on the raw data acquired was performed in the Curved-MPR Mode (Figures 1A and 1B). This digital image processing technique can also be used to determine and approve the exact position of the electrode in the cochlea. In addition to uncurling of the cochlea, slices in an orthogonal orientation to the modiolus were arranged to verify the localization of the electrode in the cochlea. In order to determine the position of the electrode in the cochlea, i.e. whether the electrode was located in the tympanic scale (inferior position in the plane of the cochlea turn), the vestibular scale (superior position in the plane of the cochlea turn) or whether there was a dislocation from one scale to another.

In order to evaluate the type of insertion of the electrode (cochleostomy or round window approach) the operational reports were evaluated. Two main periods were evaluated and compared because of a change in the principal surgical technique (because of changing the surgeon). In each period the implantations were performed only by one surgeon. The first period lasted from October 2002 to March 2008 and the second period lasted from April 2008 to September 2011. Regarding the learning curve of the surgeon a third period was defined; thus, period two was from March until December 2008 and the third period was from the beginning of 2009 to September 2011. Statistics (correlation analysis, Chi-Square-Test) was performed with SPSS 17.0 with a significance level at p<0.001.

Results

A total of 94 electrodes were evaluated regarding their exact scale location. Intracochlear positioning could be determined in all cases. As mentioned before, eight ears were excluded because of insufficient imaging quality or missing raw data. All electrodes could be evaluated regarding their exact intracochlear localization in the tympanic scale or vestibular scale or with a change between the scales. Typical images are shown in figure 2. Overall, the electrodes were localized in the tympanic scale in 68% (64 ears) of the patients and in the vestibular scale in 28% (26 ears); furthermore, 4% (4 ears) of patients showed a radiological dislocation from the tympanic to the vestibular scale. Analyzing the operation reports from 2004 until March 2008 (first period) showed that the electrodes were inserted through a classic cochleostomy approach located at different points of the basal cochlear turn. Since April 2008 (second period), all of the electrodes analyzed were inserted through the widened round window.

Interestingly, the learning curve for the new operating technique in the year 2008 could be observed in the different rates of scale implantation. The results of the different periods (first period: 2003-March 2008; second period: March 2008-December 2008; third period: 2009-up until now) are summarized in table 1.

For the first period a total of 37 ears were analyzed. They showed a rate of tympanic scale insertions of 57% (21 ears), a rate of vestibular scale insertions of 43% (16 ears) and no scale dislocations. In the second period, 15 implanted ears showed a rate of tympanic scale insertions of 60% (9 ears), a rate of vestibular scale insertions of 40% (6 ears) and no ear with scale dislocations. Since 2009, 42 ears underwent a postoperative radiological control of the implant, where 80% (34 ears) of the ears showed an insertion in the tympanic scale, 10% (4 ears) a vestibular scale insertion and 10% (4 ears) a dislocation between the two scales. These results and the statistics for the three groups are summarized in table 1. A direct comparison of the two possible operation techniques (group 1, 2004 until March 2008: conventional cochleostomy; and group 2, April 2008 up until now: round window approach) showed a reduction in vestibular scale insertion from 43% down to 18%. Therefore, tympanic scale insertions increased from 57% to 75%. These differences were highly significant (p<0.001). Interestingly, in the classic cochleostomy group no scale dislocation was observed whereas in the round window group 4% of scale dislocations occurred.

Discussion

The exact imaging and assessment of the postoperative position of
an electrode is an important element in quality control after cochlear implantation. Imaging of the temporal bone and especially of cochlea implants is challenging, not only because of the very small structures that have to be analyzed, but also because of the metal artifacts that emanate from the electrode. The development of radiological techniques for the evaluation of cochlea implant positioning has rapidly progressed over the past few years. Comparisons between computer tomography (CT) and CBCT have shown an advantage of CBCT in the normal anatomy of the middle and inner ear [8]. The feasibility of the exact determination of cochlea implant electrodes by CBCT compared to histological slices was demonstrated by Kurzweg et al. [5]. Aschendorff et al. showed that the CBCT radiography images used in postoperative electrode control after implantation with Cochlear® implants were superior to most of the CT images [7]. In most of the cases, very fine structures were not as sharply delineated in CT as in CBCT. A small radiation dose with a high resolution and a low equipment purchase price are characteristic of CBCT [3]. The low impact of the electrode artifact complements the excellent practicality of CBCT for the postoperative evaluation of cochlea implantation. The examination presented herein confirms the superior imaging quality of digital volume tomography for cochlea implants, where 92% of the electrodes evaluated were not only identified in the cochlea but their exact intracochlear position could be located, i.e. whether the implant was located in the tympanic scale, the vestibular scale or whether there was a dislocation between the scales.

The fact that tympanic scale insertions for intracochlear positioning of the implant are advantageous with regard to speech performance results shows how important precise electrode evaluations are in postoperative quality control [2]. An atraumatic insertion technique is of particular importance with regard to the increasing indications (e.g. hearing preservation implantation) for cochlea implantation. Cone-beam computed tomography enables the assessment of intracochlear trauma in terms of misplacement of the electrode in the vestibular scale or a dislocation between the scales. Penetration of the basilar membrane damages the Organ of Corti and induces a loss of sensory cells. By imaging the exact intracochlear placement of the electrode array, CBCT can assure quality control. Moreover, CBCT offers useful and important information for the further education of the surgeon.

The necessity of an atraumatic insertion has been reported by Lehnhardt since the early nineties of the last century [11]. The atraumatic insertion of implants into the tympanic scale is highly influenced by an adequate and precise choice of the cochleostomy. Adunka and Buchman reported that there is a broad spectrum of surgical techniques for cochlear implantation, especially concerning the different cochleostomy sites [12]. In terms of hearing preservation in cochlea implantation, an atraumatic insertion using the round window approach is particularly useful. Regarding the intracochlear positioning of the electrode, the present study shows the influence of the surgical procedure on the postoperative results, where conventional cochleostomy showed a higher rate of positioning in the vestibular scale than the round window approach (43% vs. 10%). The reason for the direct implant insertion into the vestibular scale in 10% of the patients is unclear; even after analyzing the operation documents and discussing this with the implanting surgeon, no problems that required this procedure to be performed were revealed. Furthermore; Todt et al. showed a rate of cochlea implant insertions directly into the vestibular scale of 3% in their series with the round window approach [13]. One reason for this could be a high-angled insertion resulting in positioning in the vestibular scale.

Table 1: An overview of the statistical data for the different results depending on the operating procedure performed. During the years 2004 to 03/2008 classic cochleostomy was done. From April 2008 onward the operating procedure was changed to a round window approach. The learning effect from 2008 over the following years can be seen by an increase in the occurrence of tympanic scale positioning.

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<tr>
<td>All together</td>
<td>37</td>
<td>15</td>
<td>42</td>
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<td>Mean age (all together)</td>
<td>41.89</td>
<td>54.73</td>
<td>48.15</td>
<td>50.16</td>
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<tr>
<td>Female</td>
<td>24 (65%)</td>
<td>9 (60%)</td>
<td>23 (55%)</td>
<td>32 (56%)</td>
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<tr>
<td>Mean age (female)</td>
<td>48.24</td>
<td>56.11</td>
<td>46.90</td>
<td>48.99</td>
</tr>
<tr>
<td>Male</td>
<td>13 (35%)</td>
<td>6 (40%)</td>
<td>19 (45%)</td>
<td>25 (44%)</td>
</tr>
<tr>
<td>Mean age (male)</td>
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<td>52.67</td>
<td>49.61</td>
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</tr>
<tr>
<td>X-ray current</td>
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<td>7.40</td>
<td>6.06</td>
<td>6.54</td>
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<tr>
<td>Position in tympani scale</td>
<td>21 (57%)</td>
<td>9 (60%)</td>
<td>34 (60%)</td>
<td>43 (75%)</td>
</tr>
<tr>
<td>Position in vestibular scale</td>
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<td>6 (40%)</td>
<td>4 (10%)</td>
<td>10 (18%)</td>
</tr>
<tr>
<td>Dislocation between scales</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>4 (10%)</td>
<td>4 (7%)</td>
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</table>

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Implant positioning in the tympanic scale was achieved in 80% of patients using the round window approach, whereas it was only achieved in 57% of patients using the cochleostomy approach. Interestingly, in the round window group, dislocations between the scales were observed in 10% of patients (4 ears), whereas none were observed for the cochleostomy approach. In addition, the effects of learning could...
be observed where, after changing the operating procedure from the classic cochleostomy to the round window approach, a higher rate of implantation into the vestibular scale was observed within the first year (cochleostomy: 43%, first year of round window approach: 18%, round window approach afterwards: 10%). This result is in good accordance with the results of Aschendorff et al. who showed the influence of the learning curve of surgeons on their implantation results [14].

A new pilot study documented the available options for identifying inner ear structures using optical coherence tomography (OCT) [15]. Optical coherence tomography can be used to optimize the anatomical orientation in cochlear implant surgery, especially as a guide for precisely locating the tympanic scale before opening the inner ear. Another study reports the experimental feasibility of navigation-guided minimal-invasive cochleostomy loco typico with flat-panel-based volume computed tomography (fd-VCT) [16]. Using high-resolution CT and robotic tools as a positioning platform for surgical instruments could be a feasible approach for performing highly precise cochleostomy. Although these procedures are currently still experimental they could have important influences on future surgical techniques. In conclusion, the scope of cone-beam tomography in the evaluation of intracochlear positioning of cochlea electrodes was shown. The additional influence of the operating technique could result in a higher rate of implantation in the vestibular scale in classical cochleostomy compared to the round window approach.

References