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Research paper

X-ray microtomographic confirmation of the reliability of CBCT in identifying the scalar location of cochlear implant electrode after round window insertion

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A B S T R A C T

Cone-beam computed tomography (CBCT) plays a key role in cochlear implantation in both planning implantation before surgery and quality control during surgery due to the high spatial resolution and convenience of application in the operation theater. We recently designed a novel, highresolution cone-beam acquisition system that has been tested in temporal bones with cochlear implantation to identify the scalar localization of the electrode arrays. The current study aimed to verify the reliability of the experimental CBCT set-up using high-resolution in vitro X-ray microtomography (μCT) imaging as a reference. Nine human temporal bones were studied by inserting a straight electrode of a cochlear implant using the round window approach followed by sequential imaging using experimental CBCT and μCT with and without 1% iodine as the contrast agent. In the CBCT images, the electrodes were located in the scala tympani and near the lateral wall in all temporal bones. In the μCT images, the cochlear fine structures, including Reissner's membrane, stria vascularis, spiral ligament, basilar membrane, spiral limbus, osseous spiral lamina, and Rosenthal's canal that hosts the spiral ganglion cells, were clearly delineated; the electrode array avoided the lateral wall of the scala tympani in the hook region and then ran along the lateral wall of the scala tympani without any exception, a feature that was also detected in a temporal bone with ruptures in the basilar and Reissner's membranes. In conclusion, the current in vitro μCT imaging system produced high-quality images that could demonstrate the fine cochlear structures faithfully and verify the reliability of a novel experimental CBCT set-up aimed for clinical application in identifying the scalar localization of the electrode array. The straight electrode is safe for cochlear structures with low risk of translocation and is suitable for atraumatic implantation, although a large gap between the contacts and the modiolus exists.

1. Introduction

Since the first report on the visualization of the electrode-modiolus relationship after cochlear implantation using a C-arm-based radiographic device by Husstedt et al. (2002), cone-beam computed tomography (CBCT) has been used in the clinic to control the scala location of electrodes (Pearl et al., 2014). The advantage of CBCT over conventional multiple-detector CT (MDCT) is the isotropic voxel and higher spatial resolution, which are critical for identifying the electrode position accurately in the cochlea

Abbreviations: CBCT, cone-beam computed tomography; FOV, field of view; MDCT, multiple-detector computed tomography; RWM, round window membrane; μCT, X-ray microtomography

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in post-operative imaging of the electrode in the operating theater. CBCT systems also have the potential to be mobile and relatively cheap, making them suitable to equip the operating theater. However, the fine structures of the cochlea, which are critical landmarks to identify the position of cochlear electrode arrays intra-cochlearly, were not visualized in previous studies. We recently designed a novel, high-resolution acquisition system in CBCT that involves a pause in the rotation during each X-ray exposure (Zou et al., 2014b). A combination of copper and aluminum filters was used to adjust the contrast of images (Olubajimi, 2011). Imaging parameters were optimized to show the fine structures inside the cochlea (Zou et al., 2014a).

It is necessary to confirm the accuracy of CBCT in identifying the scala location of the electrode array at the level of histology before the application is implemented in the clinic. Previously, histological studies have been used to verify the reliability of commercial CBCT in the scalar localization of the electrode array as well as dislocation and damage in the soft tissue (Marx et al., 2014). However, sectioning the temporal bone with the electrode installed is a difficult procedure because the hard metal would definitely cause artifacts, including morphological changes in the soft tissue. Again, the reaction between the electrode coating and embedding compounds distorted the cochlear morphology (Teymouri et al., 2011). Additionally, showing all cochlear structures using serial sectioning and 3-dimensional reconstruction of the slices is a time-consuming process. X-ray microtomography (μCT) is an excellent tool to confirm the accuracy of CBCT by providing micrometer-scale resolution without actual histological sectioning (Postnov et al., 2006). μCT has also been applied to validate the effect of MDCT in estimating the scalar location of the electrode array (Teymouri et al., 2011). This advanced imaging technique was utilized to evaluate the potential intracochlear trauma caused by electrode insertion (Nguyen et al., 2012). The present work was aimed to compare the temporal bone images after cochlear implantation acquired using the novel CBCT to perform μCT with and without contrast agent to visualize the fine structures of the cochlea such as Reissner's membrane, stria vascularis, spiral ligament, and basilar membrane.

2. Materials and methods

2.1. Electrodes and temporal bone procedure

Nine human temporal bones were used in imaging. All of the specimens were donated to the University of Tampere for scientific use and fulfilled all of the requirements of the Declaration of Helsinki that were developed by the World Medical Association and updated at the 64th WMA General Assembly, Fortaleza, Brazil, in 2013, regarding the ethical use of human materials (2014). The following electrodes were provided by MED-EL (Table 1). The standard electrode has 12 pairs of stimulating contacts made of platinum with an active stimulation length of 26.4 mm (2.4-mm contact separation). Flex28 is thinner and more flexible than the standard electrode and has 7 pairs of stimulating contacts in the basal part and 5 single lines of contact in the apical part with an active stimulation length of 23.1 mm. The third type is an experimental electrode array with 36 stimulating contacts arranged in a single line and extended with an active stimulation length of 28 mm. More detailed information on the electrode is provided in Table 1. Six formaldehyde-preserved human temporal bones were implanted with these electrodes in the Temporal Bone Lab of Tampere University Hospital and three in the Temporal Bone Lab of Helsinki University Central Hospital through round window membrane (RWM) insertion. The round window niche was exposed through posterior tympanotomy, and most of the anterior bony overhang of the round window niche was removed. A transverse incision was made across the RWM, and a defined electrode was carefully inserted into the scala tympani through the incised RWM. The remaining part of the electrode was coiled inside the drilled mastoid cavity and packed with tissue pieces. Two temporal bones were infused with 1 ml of 1% iodine (dissolved in absolute ethanol) into the scala tympani beside the electrode for μCT imaging after CBCT imaging.

2.2. CBCT imaging of temporal bones

Images were obtained with a specially designed CBCT set-up using an x-ray source (Superior SXR 130-15-0.5; Superior X-ray Tube Co., Woodstock, USA), a flat-panel detector (Varian PaxScan 2520D, Varian Medical Systems, Salt Lake City, USA) and a rotating sample stage. In the standard CBCT machine, the spatial resolution may be limited by motion artifact caused by the rotating c-arm during exposure. The novelty of the experimental set-up is that the multiple frames were obtained by rotating the sample stage in a step-and-shoot manner where the rotation is stopped during each exposure. Imaging parameters used in this study were as follows: number of frames = 900, tube voltage = 88 kV, tube current = 11 mA, exposure length per frame = 50 ms, filtration = 0.5 mm copper + 2.5 mm aluminum, source-to-image distance = 1 m, magnification factor = 1.17, voxel size = 0.1 mm, field of view (FOV) = 60 × 60 mm. The distance between each electrode contact of an experimental electrode array with 36 stimulating contacts and the modiolus was measured in the transmodiolar cross sectioning images using the axial images to identify the location of the contacts.

2.3. μCT imaging of temporal bones

The μCT images were acquired using the Zeiss Xradia MicroXCT-400 (Zeiss, Pleasanton, USA) guided by the XMController software. μCT imaging was performed by three main parameter configurations using no filters, a 140-kV source voltage, a 71-μA current, a pixel binning of 2, 1600 projections and a 360° projection angle. All of the specimens were imaged using a 0.4 × large field-of-view objective resulting in a 22.6-μm pixel size. To examine the fine details with higher magnification, three iodine-stained specimens were imaged with a 4 × objective, resulting in 13.4-μm and 3.6-μm pixel sizes. Exposure times were 4 s, 12 s and 30 s, respectively. To diminish anisotropic changes in the direction of the X-ray beam

Table 1
Technical specifications of the electrode types.

	Standard array	Experimental array with 36 contacts	Flex28
Active stimulation length	26.4 mm	28	23.1
Number of contacts	24 (12 pairs)	36 (One line of contacts)	19 (7 pairs and 5 single line)
Contact separation	2.4 mm	0.8 mm	2.1 mm
Diameter at basal end	1.3 mm	1.3	0.8
Dimensions at apical end	0.5 mm	0.5	Oval shaped (0.48/0.36)
Number of operations	4	1	4