A New Computed Tomography Method to Identify Meningitis-Related Cochlear Ossification and Fibrosis before Cochlear Implantation

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Abstract

Objective. To develop a new method to determine the presence of intracochlear ossification and/or fibrosis in cochlear implantation candidates with bilateral profound deafness following meningitis.

Study Design. Diagnostic test assessment.

Setting. A university hospital.

Subjects and Methods. This study involved 15 ears from 13 patients with profound deafness following meningitis who underwent cochlear implantation. These ears showed normal structures, soft tissue, partial bony occlusion, and complete bony occlusion in 4, 3, 2, and 6 ears, respectively. We measured radiodensity in Hounsfield units (HU) using 0.5-mm-thick axial high-resolution computed tomography image slices at 3 different levels in the basal turn, the fenestration, and inferior and ascending segment sites, located along the electrode-insertion path. Pixel-level analysis on the DICOM viewer yielded actual computed tomography values of intracochlear soft tissues by eliminating the partial volume effect. The values were compared with the intraoperative findings.

Results. Values for ossification (n = 12) ranged from +547 HU to +1137 HU; for fibrosis (n = 11), from +154 HU to +574 HU; and for fluid (n = 22), from −49 HU to +255 HU. From these values, we developed 2 presets of window width (WW) and window level (WL): (1) WW: 1800, WL: 1100 (200 HU to 2000 HU) and (2) WW: 1500, WL: 1250 (500 HU to 2000 HU). The results using these 2 presets corresponded well to the intraoperative findings.

Conclusion. Our new method is easy and feasible for preoperative determination of the presence of cochlear ossification and/or fibrosis that develops following meningitis.

Keywords

cochlear implant, cochlea ossification, meningitis, Hounsfield unit, HRCT

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Cochlear implantation is an accepted method of auditory rehabilitation for patients with profound hearing loss after meningitis,¹⁻⁴ and improvements in surgical technique such as the intact canal wall drill-out procedure have enabled the successful placement of electrodes around the modiolus even in totally ossified cochleas.⁵⁻⁸ However, surgeons occasionally encounter severe ossifications, and insertion of electrodes with the advanced drill-out technique may be problematic. Complete assessment of the extent of ossification prior to surgery would be valuable in determining the most appropriate procedure, minimizing drilling into the ossified cochlea for electrode insertion, and avoiding unnecessary damage to adjacent tissues.

There have been many reports on cochlear imaging in cochlear implantation,⁹⁻¹⁴ but only a few reports are available on preoperative evaluation for intracochlear lesions. We have previously described a method using computed tomography (CT) image reconstruction around the modiolar axis for evaluating the patency of the intracochlear spaces.¹⁵,¹⁶ The first
article described the effectiveness of using a CT workstation to reconstruct CT images crossing the modiolar axis in various planes in assessing cochlear patency. The method was developed in the second article, which described how multiple crossing slices around the modiolar axis were rotated to generate a rotating CT movie. This CT movie was very useful for an intuitive understanding of the position and degree of ossification in the intracochlear spaces, particularly in the ascending-to-superior portion, which is not well visualized on common high-resolution computed tomography (HRCT) axial views. This method, however, requires complicated procedures such as transfer of digital images to a personal computer, multiplanar reconstruction requiring reformattting software, and conversion to a movie and thus is time-consuming. In the current study, we have developed a new method, which is quicker and easier to perform, for identifying cochlea fibrosis and/or ossification.

**Methods**

**Patients**

Study subjects included 15 ears from 13 patients, 10 adults and 3 children, with profound deafness due to meningitis who underwent cochlear implantation at our hospital from October 2002 through August 2011. Preoperative HRCT examination was performed within 1 month prior to surgery. Abnormal findings suggestive of fibrosis or ossification were present in the intracochlear space in 7 ears on preoperative CT. Definitive intraoperative findings were normal structures, soft tissue alone, partial bony occlusion, and complete bony occlusion in 4, 3, 2, and 6 ears, respectively. The details are shown in Table 1. The 7 suspected ears and 2 ears without such abnormality required drill-out procedures for electrode insertion. Electrodes were completely inserted in 12 ears, whereas they were incompletely inserted in 3 ears because of the presence of complete bony occlusion. This study was approved by the institutional review board of the University of Tokyo Hospital.

**CT Examination**

High-resolution axial projection images of the temporal bone were obtained with 2 multi-helical CT scanners. A 4-detector-row CT scanner (Toshiba Aquillon 16, New York, NY) in helical scan mode (0.5-mm slice width, 120 kV, 200-300 mA, pitch 3:1) was used in 10 ears, and a 320-detector-row CT scanner (Toshiba Aquillon ONE) in volume scan mode (0.5-mm slice width, 120 kV, 100 mA) was used in 5 ears. The reconstruction spacing was 0.1 mm in both scanners. The raw data were transferred to a CT workstation (Advantage Workstation version 4.0; GE Medical Systems, Milwaukee, WI).

We measured the radiodensity in Hounsfield units (HU) by using a tool in the CT workstation that showed CT values pixel-by-pixel on the line specified, a straight line perpendicular to the basal turn (Figure 1). The partial volume effect is a considerable and significant artifact in the analysis of temporal bone CT imaging and is composed of 2 principal values: bone (approximately 1200 HU) and fluid (approximately 0 HU). Partial volume effect means that the radiodensity is evaluated as a weighted average value if different CT values coexist in the same pixel. In the analysis using this tool, a “steep slope” (marked with a dashed line in Figure 1) was considered to reflect the partial volume effect. Conversely, a “flat slope” (marked with a solid line) was considered to reflect tissue type in the intracochlear space. The CT value remains unchanged if the same CT values extend evenly beyond the limit of space resolution of

**Table 1. Patient details and clinical presentation.**

<table>
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<tr>
<th>No.</th>
<th>Age at deafness</th>
<th>Age at operation</th>
<th>Implant side</th>
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<th>Surgical findings</th>
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<tr>
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<tr>
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Abbreviations: CT, computed tomography; FE, full electrode insertion; PE, partial electrode insertion.
The slice thickness. Therefore, we found the most flat slope by finely adjusting the line. Consequently, all standard deviations of CT values of the flat slope were less than 100 HU. In a 512 matrix with a field of view of 8.0 cm, 1 pixel is a square with a side of 0.156 mm (=80/512). Thus, the size of 5 pixels exceeded the slice width of 0.5 mm; this required elimination of the partial volume effect. We adopted the average CT value of 5 pixels in the flat slope as the actual CT value. This method for eliminating the partial volume effect was developed by trial and error and may be a novel method.

Using this method, we measured the CT value at 3 different levels in the basal turn, including the fenestration site and the inferior and ascending segment sites, that were located along the electrode-insertion path (Figure 2). The values measured were compared with the intraoperative findings. The classification of tissue type as fluid, fibrosis, or ossification was first based on the surgeon’s subjective findings under magnification. In addition, we considered specific intraoperative findings; for example, we considered the site requiring drill-out as “ossification” and the site where the surgeon sensed a resistance when inserting the electrodes as “fibrosis.”

### Results

The study results are shown in Table 2. The acquired CT values of each intracochlear state are shown in Figure 3. Values for ossification (partial and complete; n = 12) ranged from +547 HU to +1137 HU; for fibrosis (n = 11), from +154 HU to +574 HU; and for presence of fluid (n = 22), from −49 HU to +255 HU. Almost all pixels ranged from 0 HU to +2000 HU. Ossification was separated from fibrosis at the level of approximately 500 HU, and fibrosis occurred from the level of approximately 200 HU. Intraoperative findings revealed that tissue of approximately 500 HU displayed fibrosis that was nearly ossified or partial ossification, so 500 HU was considered the delimitation of fibrosis and ossification. In addition, the 2 sites enclosed by a circle in Figure 3 were both described as “osseous fibrosis” by the surgeon but required drill-out. Therefore, sites exceeding 500 HU required drill-out in all cases. Under the condition in which the limits were 200 HU and 500 HU, the sensitivity, specificity, and positive and negative predictive values of predicting ossification on HRCT with 95% confidence intervals were 100% (82%-100%), 95.2% (90%-95%), 85.7% (70%-86%), and 100% (95%-100%), respectively. On the other hand, the sensitivity, specificity, and positive and negative predictive values of predicting fibrosis on HRCT with 95% confidence intervals were 75.0% (53%-88%), 92.9% (87%-97%), 75.0% (53%-88%), and 92.9% (87%-97%), respectively. In addition, both the sensitivity and specificity of the need for drill-out were 100%. In the receiver operating characteristic (ROC) curve analysis, the area under the ROC curve (AUC) is 0.92 between fibrosis...
(n = 11) and fluid (n = 22), while the AUC is 0.99 between ossification (n = 12) and fibrosis (n = 11).

**Presets of Window Width and Window Level to Distinguish between Ossification with and without Fibrosis**

From these values, we developed 2 presets of window width (WW) and window level (WL): (1) WW: 1800, WL: 1100 (200-2000 HU) and (2) WW: 1500, WL: 1250 (500-2000 HU), to evaluate the intracochlear space (Figure 4). Preset 1 displays densities less than 200 HU as pure black, and preset 2 displays densities less than 500 HU as pure black. In other words, preset 1 visualizes fibrosis + ossification with densities exceeding 200 HU and preset 2 visualizes only ossification with densities exceeding 500 HU. Examples of various views are shown in Figure 5. Image A is a general view (WW: 4000, WL: 400) of temporal bone HRCT. Image B is a view focused in the range from 0 HU to 2000 HU. The image becomes clearer by enhancing the contrast. Note that the partial volume effect can be identified as blurred lines peripheral to bone. Image C is a view in preset 1 (WW: 1800, WL: 1100) that reveals densities exceeding 200 HU. Gray shadows visualized in the intracochlear space could be fibrosis or ossification. Image D is a view in preset 2 (WW: 1500, WL: 1250) that reveals densities exceeding 500 HU. The remaining shadow could be only ossification. Thus, fibrosis is visualized in preset 1 but not preset 2. The results using these 2 presets corresponded well with the intraoperative findings.

**Representative Cases**

**Case 1.** The patient (No. 11 in Table 1) was a boy without any remarkable history who developed bacterial meningitis...
caused by _Haemophilus influenzae_ at 1 year 10 months and became profoundly deaf. Cochlear implantation was performed in both ears at 2 years. Implantation in the right ear is described here. The HRCT images suggested severe ossification in the lower-to-ascending portion of the basal turn.

We failed to fenestrate at the typical point anterosuperior to the round window niche because of severe ossification. The transcanal drill-out approach demonstrated that the inferior segment was filled with fibrous tissue. Drilling ended at 9 o’clock from the round window niche because of the complete ossification at the ascending portion. Only 11 intracochlear electrodes of Nucleus CI 24 RE could be inserted.

Preset 1 and preset 2 images are shown in Figure 6. Preset 1 images show fibrosis near the round window niche (solid circle). Note the space in the scala vestibule (dotted arrow). Preset 2 images show complete ossification in the inferior segment (solid arrows). Note the space in the ascending portion (arrowheads). The HRCT findings using the 2 presets corresponded well to the intraoperative observations.

**Discussion**

The major finding of the present study was that evaluation of intracochlear lesions using the preoperative HRCT imaging technique with 2 presets had the advantage of identifying the appearance of material such as fluid, fibrosis, and ossification in the cochlea as well as distinguishing clearly between fibrosis and ossification. In particular, preset 2 visualized only ossification, thereby identifying the site requiring drilling. Evaluation of the extent of both the ossified and fibrous regions on HRCT using the 2 presets corresponded well with the intraoperative findings in all 15 ears.

HRCT and magnetic resonance imaging (MRI) are used to assess cochlear patency in the preoperative assessment of cochlear implant candidates with a history of meningitis. Currently, MRI is considered to have better sensitivity and specificity for predicting cochlear patency than does HRCT.17-19 Theoretically, soft-tissue labyrinth abnormalities can be identified using MRI but not HRCT, and fine bony details of the temporal bone can be demonstrated using HRCT. Recent research has shown that gadolinium-enhanced T1-weighted MRI is useful for detecting peracute labyrinthitis of the cochlea.20 Three-dimensional reconstruction of CT images and reconstruction around the modiolar axis (our previous studies) have been reported to demonstrate ossified obstruction, but not fibrotic obstruction, in the intracochlear space.14-16 HRCT is superior to MRI for visualizing osseous structures, as well as mastoid and middle ear anatomy, whereas MRI is more useful for visualizing intracochlear fluid, as well as semicircular canals, the cerebellopontine angle, and the vestibulocochlear nerve. Taken together, a combination of HRCT and MRI is considered essential for evaluation of the intracochlear space in patients with deafness due to meningitis.

The current study was conducted to determine whether HRCT could be used to evaluate cochlear patency quickly and easily without additional processes such as reconstruction of CT images and to differentiate clearly between fibrosis and ossification. First, we explored how to measure years before she underwent cochlear implantation in the right ear. The HRCT images suggested severe ossification in the inferior segment of the basal turn.

We explored the promontory via posterior tympanotomy and found that the scala tympani anterior to the round window niche were filled with fibrous tissue. With the transcanal drill-out technique, we found complete ossification in the lower portion that ended at 8 o’clock after creating space for electrode insertion. All 22 active electrodes of the Cochlear N24 device were placed around the modiolus.

Preset 1 and preset 2 images are shown in Figure 7. Preset 1 images show fibrosis near the round window niche (solid circle). Note the space in the scala vestibule (dotted arrow). Preset 2 images show complete ossification in the inferior segment (solid arrows). Note the space in the ascending portion (arrowheads). The HRCT findings using the 2 presets corresponded well to the intraoperative observations.

**Figure 3.** Plots of the computed tomography values of each intracochlear state. Note that ossification is separated from fibrosis at the level of approximately 500 HU, and fibrosis occurs from the level of approximately 200 HU.

**Figure 4.** The computed tomography values of the tissue (fluid, fibrosis, or ossification) in the intracochlear space and 2 presets (preset 1 and preset 2).
actual CT values in the intracochlear space. Initially, we attempted to measure CT values by using the region-of-interest tool on a CT workstation, but we were unable to establish an objective and reproducible measuring method because the problem of the partial volume effect could not be resolved. It is well known that the partial volume effect is a considerable and significant artifact in analyzing temporal bone CT imaging. Therefore, we developed a novel method of measuring CT values by performing pixel-level analysis on a CT workstation by canceling the partial volume effect. Then, we used these values to determine window width and level presets, which differentiated between fibrosis and ossification. This finding contradicts the previous consensus that fibrosis cannot be differentiated from ossification on CT images. To the best of our knowledge, this is the first study to determine actual CT values of the material such as fluid, fibrosis, and ossification in the intracochlear space.

According to this method, values for fluid range from approximately −50 to +200 HU and are not limited to 0 HU. This might be because micro soft tissue such as stria vascularis and peracute changes of labyrinthitis were included in the analysis. Further, the negative value might reflect statistical deviation based on the value for water of 0 HU or unnoticeable inclusion of fat tissue. There is an overlap of HU values between ossification and fibrosis as well.
as between fibrosis and fluid. The change from fluid to fibrosis and then to ossification is gradual, so it is difficult to clearly classify each tissue type. In addition, the classification was based on the surgeon’s subjective findings in this study. The results reflecting these overlaps are considered valid for these reasons. We set the limits between fluid and fibrosis and between fibrosis and ossification as the round numbers 200 and 500, respectively. Of note, 500 HU was revealed as the value above which drill-out was required. We consider this an important finding because the cutoff value of 500 HU has objective and practical application in the determination of whether drill-out is required.

Advantages of this new method are simplicity and intuitiveness. HU are identified as universal values and are comparable among different CT scanners. Thus, this method can be performed immediately by altering CT ranges to preset 1 (WW: 1800, WL: 1100) and preset 2 (WW: 1500, WL: 1250). No additional procedures such as reconstruction of CT images are required. In addition, this new method makes it possible to understand cochlea patency intuitively, because fibrosis and ossification are visualized as shadows on CT images as opposed to signal defects on MRI images. MRI is also more demanding than HRCT because of several factors, such as higher cost, necessity of sedation, and longer imaging time. Taken together, this new method using only HRCT images is potentially useful.

Of note is the fact that HRCT images in the current study were acquired with a slice thickness of 0.5 mm. Considering that the mean height of the scala tympani is 1.3 mm,21 a slice thickness of less than 0.75 mm is required to evaluate intracochlear patency. In addition, preset 1 and preset 2 images cannot discriminate between the scala tympani and the scala vestibule because the basement lamina becomes invisible when focusing on narrow ranges. However, this problem may be resolved by synchronizing the same slices with a general view (eg, WW: 4000, WL: 400) on the CT workstation. This method does not yield clear images of the ascending-to-superior portion of the basal turn, which is a critical site adjacent to the facial nerve, and middle turn requiring particular attention during electrode insertion. This is an inevitable problem with the use of axial images. Combined use of the present method and the rotating CT movie reported in our previous article would allow visualization of the whole intracochlear space, including the ascending-to-superior portion.

We assume that by superimposing preset 1 and preset 2 images (in different colors) on the common axial CT image, complete assessment of the intracochlear space can be possible using reconstruction of a 3D image. To verify this hypothesis, further accumulation of cases is needed.

Conclusion
We determined actual CT values of materials such as fluid, fibrosis, and ossification in the intracochlear space. Our new method using preset window level and width values is easy and feasible for preoperative determination of the presence of cochlear ossification and fibrosis that develops following meningitis.

Author Contributions
Kazunori Ichikawa, data collection and review, conception of study design, writing; Akinori Kashio, surgery, revision of initial manuscript; Harushi Mori, review of images, editing of manuscript, study design involving radiological techniques; Atushi Ochi, surgery, revision of initial manuscript; Shotaro Karino, surgery, revision of initial manuscript; Takashi Sakamoto, surgery, revision of initial manuscript; Akinobu Kakigi, surgery, revision of definitive manuscript; Tatsuya Yamasoba, proposal of the study, surgery, revision of definitive manuscript.

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