Detection of Labyrinthine Fistulas in Human Temporal Bone by Virtual Endoscopy and Density Threshold Variation on Computed Tomographic Scan

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Objective: To assess the sensitivity of the routine computed tomographic (CT) scan of the temporal bone coupled to a virtual endoscopy, with density threshold variation, in detecting small fistulas in human temporal bone specimens.

Design: Single-blind, before-after trial.

Setting: This study was carried out in a research laboratory in collaboration with a radiology department.

Patients: Five human adult temporal bone specimens were included.

Interventions: The fistulas were created with calibrated burrs (0.3, 0.5, and 0.8 mm) in the 3 semicircular canals and in the promontory of 3 temporal bones. Two other temporal bones served as controls. All bones underwent CT scan (1-mm section thickness) before and after dissection. Three-dimensional images were obtained from CT scan native axial views at different density reconstruction thresholds. The virtual endoscope was placed in the middle ear cavity looking to the inner ear wall. The threshold at which a bony defect appeared on virtual endoscopic images (opening threshold in Hounsfield units [H]) was noted for each location.

Main Outcome Measures: Opening thresholds before and after dissection.

Results: On standard axial views, fistulas smaller than 0.5 mm were not visualized. By virtual endoscopy, all fistulas could be visualized. The opening threshold decreased after fistula creation in the semicircular canals (1244±50.5 H [n=36] vs 778±52.4 H [n=34]; P<.001; 1-way analysis of variance and Dunnett multiple comparisons posttest) and in the promontory (1541±37.8 H [n=12] vs 1334±35.1 H [n=8]; P<.001). The opening thresholds in the control specimens remained unchanged after dissection.

Conclusion: Virtual endoscopy with variation of reconstruction threshold allows the detection of small labyrinthine fistulas with diameters of 0.3 mm or smaller.


aboral communications between the inner and middle ear compartments. Their clinical diagnosis is difficult, because typical clinical signs are not always present.1,2 Imaging exploration, including computed tomographic (CT) scan and magnetic resonance imaging, inconsistently provides evidence of the abnormal communication by showing a bony defect in the labyrinthine wall or, in rare cases, a pneumolabyrinth.1,3 Although data on the size of the labyrinthine fistula are rarely available in the published series,1-4 it can be expected that the sensitivity of the CT scan is highly dependent on the size of the fistula. Only bony defects with a diameter equal to or greater than the section thickness can be detected with certainty on high-resolution CT scans with contiguous sections.3 Surgical exploration is often necessary in cases of invalidating clinical signs without radiologic arguments.8 Thus, the need for an imaging method that increases the sensitivity of labyrinthine fistula detection is evident.

Virtual endoscopy based on CT scan data has been described for the exploration of the middle and inner ear cavities.7-10 This technique has the advantage of visualizing the anatomical structures with a 3-dimensional (3-D) view that resembles the surgical field, thus facilitating the location of abnormalities during surgery.9,10 The data-processing algorithm that allows virtual endoscopy is currently available on many CT scan workstations.9,11 The threshold variation associated with this technique allows a reconstruction of the bony structures, depending on their density and thickness.11

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By progressively increasing the reconstruction threshold, an opening of the labyrinthine wall first appears in thinner zones and gradually extends to thicker regions (Figure 1). The aims of this study were to use this property to detect small labyrinthine bone erosions and to evaluate the sensitivity of virtual endoscopy associated with threshold variation on CT scan in detecting calibrated labyrinthine fistulas in human temporal bone specimens.

METHODS

Experiments were performed in 5 adult human temporal bone specimens. Two temporal bones served as controls (temporal bone A: without mastoidectomy; temporal bone B: with mastoidectomy and without fistula). In the 3 remaining temporal bones (C, D, and E), fistulas were made by calibrated burrs (0.3, 0.5, and 0.8 mm) in the semicircular canals and the promontory (Figure 2 and Table). All temporal bones underwent a CT scan with 1 acquisition before and 1 after dissection. Images were analyzed twice by the same radiologist (J.-L.B.), first with a single-blind design and subsequently with the knowledge of the fistula locations. A high-resolution CT scan was performed with spiral acquisition on a system with 4 detector rows (Light Speed; General Electric Medical Systems, Buc, France). The acquisition settings were as follows: 140 kV; 200 mA; high-quality protocol; field of view, 250 mm; section thickness, 1 mm; 3.75-mm shift per rotation; and 1 rotation per second.

Two postprocessing analysis protocols were used. The first was the axial view protocol. In this protocol, the postprocessing program enhanced the density resolution (same settings as for the axial view protocol, with a standard filter). A viewer with a 2-dimensional and multiple projection reconstruction was used. In this protocol, the results were reported as visualization or absence of visualization of the fistula.

The second protocol was a virtual endoscopy protocol. In this protocol, a spatial resolution postprocessing program was applied (field of view, 100 mm; section thickness, 1 mm; section interval, 0.6 mm; high-resolution filter, Bone + [General Electric Medical Systems]). A viewer with a 2-dimensional and multiple projection reconstruction was used. In this protocol, the results were reported as visualization or absence of visualization of the fistula.

Figure 1. Principal of the virtual endoscopy with threshold variation. A 3-dimensional (3-D) image of the temporal bone is obtained from native axial computed tomographic (CT) scan views. A virtual endoscopy is performed by placing the viewer in the middle ear cavities and looking to the lateral semicircular canal. On the top image, the white arrow shows the direction of the 3-D view on a native axial CT scan of temporal bone A (control). The bottom images show the virtual endoscopic views centered on the lateral semicircular canal and obtained at 4 different reconstruction thresholds (927 to 1059 Hounsfield units [H]). With an increase of the reconstruction threshold with 1-H increments, a virtual opening in the labyrinthine wall (black arrow) is observed at 963 Hu. This value was defined as the opening threshold, which enlarges as the threshold increases (black arrows).

Figure 2. Radical mastoidectomy cavity with calibrated fistulas in temporal bone D. Arrows indicate the 0.4-mm-diameter fistulas drilled with calibrated burrs. 1, Anterior semicircular canal (SCC); 2, lateral SCC; 3, posterior SCC; and 4, promontory.
Table. Size of the Fistulas in the Temporal Bone Specimens

<table>
<thead>
<tr>
<th>Fistula Size, mm</th>
<th>Superior SCC</th>
<th>Lateral SCC</th>
<th>Posterior SCC</th>
<th>Promontory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal Bone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.5</td>
<td>0.5</td>
<td>NA</td>
<td>0.5</td>
</tr>
<tr>
<td>D</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>E</td>
<td>NA</td>
<td>0.8</td>
<td>0.3</td>
<td>NA</td>
</tr>
</tbody>
</table>

Abbreviations: NA, not applicable; SCC, semicircular canal.
*Fistulas were visualized on axial views. All fistulas were visualized with the virtual endoscopy protocol.

RESULTS

AXIAL VIEW PROTOCOL

With the single-blind analysis, no fistula smaller than 0.5 mm was visualized. Among the 0.5-mm fistulas, the only one localized on the lateral semicircular canal was visualized. The knowledge of the fistula location did not enhance the sensitivity of the detection. No false-positive images were reported on control temporal bones.

VIRTUAL ENDOSCOPY PROTOCOL

With the single-blind experimental setting, the opening thresholds of the semicircular canals and the promontory were not altered before and after dissection in the control temporal bones without mastoidectomy or with mastoidectomy and without fistula (Figure 3). After fistula creation, the opening thresholds decreased in the semicircular canals (1244±50.5 H [n=36] before fistula vs 778±52.4 H [n=34] after fistula, P<.001; Figure 3).

All fistulas (0.3-0.8 mm) were evidenced by virtual endoscopy (Figure 4).

On the promontory, the virtual endoscopic images were more difficult to interpret because of a variable bone thickness, depending on the examined point. By increasing the reconstruction thresholds, a progressive opening of the oval and the round windows was observed. Fistulas on the promontory appeared as a notch on the inferior ridge of the oval window (Figure 4). The threshold at which the notch appeared was considered the opening threshold for this site. This threshold also decreased after fistula creation (1541±37.8 H [n=12] before fistula vs 1334±35.1 H after fistula [n=8]; P<.001; Figure 3).

To investigate false-positive images, virtual endoscopic images of each site before and after fistula creation were compared at the same time as the reconstruction threshold, corresponding to the opening threshold.
after fistula creation. This comparison did not show any opening of labyrinthine wall on the images obtained before fistula creation while all fistulas were visualized (Figure 5).

With the knowledge of the fistula location, the opening thresholds remained significantly lower after fistula creation in the semicircular canals, but this difference did not reach significance in the promontory (data not shown). The comparison of the virtual endoscopic images before and after the dissection in this experimental setting evidenced the fistulas in the same locations without false-positive images (data not shown).

This study assessed the value of CT scan–based virtual endoscopy with reconstruction threshold variation in detecting small labyrinthine fistulas. With this technique, we could detect small fistulas (<0.5 mm) that were undetectable on axial CT scan views. This image postprocessing technique, which was applied to images that were acquired with a routine protocol, appeared to enhance the sensitivity of the fistula detection. No false-positive result was obtained by comparing images before and after dissection in the control specimens without fistulas.

Two types of fistulas can be distinguished. Labyrinthine fistulas are defects of the bony labyrinth and expose the labyrinth to the middle ear space. The most frequent are located in the lateral semicircular canal and are caused by middle ear cholesteatomas. In this case, the perilymphatic space is intact, and the clinical signs are related to the pressure changes in the middle ear transmitted to the vestibule through the fistula. Perilymphatic fistulas are abnormal communications between the middle ear space and the perilymphatic space. They are frequently located in the oval or the round window and lead to perilymph leakage to the middle ear space.
clinical signs are related to inner ear fluid leakage and the consequent decrease in fluid pressure. These fistulas are frequently traumatic in adults and are related to malformations in children (ie, a large vestibular aqueduct connecting the cerebrospinal fluid to the inner ear compartments). Both CT scan and magnetic resonance imaging can only confirm the diagnosis in rare cases of large bony defect or pneumolabyrinth. Their sensitivity depends on the section thickness and especially on the interval of sections. However, even with overlapping sections of 1 mm (0.5-mm interval) or spiral acquisition, small fistulas cannot be detected with certainty. In cases of typical signs (the fistula sign) with no imaging confirmation, surgical exploration is indicated. In case of nonspecific clinical signs, diagnostic and therapeutic attitude may vary, depending on the severity and progression of the signs.

Virtual endoscopy based on CT scan data yields 3-D images that closely resemble surgical views. This technique has demonstrated its utility in the management of middle ear diseases. Briggs et al applied this technique to labyrinthine fistulas associated with middle ear cholesteatoma. In their study, fistulas were visualized on axial views and could be located by navigation inside the inner ear structures. However, their images did not correspond to a surgical view and were less useful for the preoperative planning than those obtained from the middle ear space as in our protocol. Those authors chose to navigate inside the inner ear probably because the presence of the cholesteatoma altered the virtual endoscopy images and hampered the detection of the fistula.

The detection of small fistulas on CT scan is usually based on high-spatial-resolution data processing. By these protocols, fistulas smaller than the section thickness cannot be detected. In the present study, we used a density resolution protocol to detect fistulas in the otic capsule. This protocol appeared to enhance the sensitivity of the CT scan by exploiting the data on bone density variation in case of a fistula smaller than the section thickness. This bone density alteration was measured as a decrease in the opening threshold after fistula creation.

Although our protocol appears to enhance the sensitivity of fistula detection, it has several limitations. The middle ear navigation should be exhaustive and the view angle should be perpendicular to the fistula for an optimal detection. Consequently, this method is time consuming. Moreover, this method may yield false-positive images in case of bone erosion without fistula or in regions such as the promontory, where the bone thickness is variable, depending on the examined point. Indeed, on the promontory, the progressive increase of the reconstruction threshold corresponds to a progressive virtual opening of the oval and round windows extending to the promontory (Figure 5), and the fistula can be visualized as a notch on one of the windows (Figure 4). Tympanosclerosis, a thick middle ear mucosa, and any other change of bone density (eg, otosclerosis, Paget disease, and osteogenesis imperfecta) may also make the images difficult to interpret.

In conclusion, our postprocessing protocol, which enhances bone density resolution instead of spatial resolution, significantly improved the sensitivity of labyrinthine fistula detection with no additional irradiation. This method has the advantage of visualizing the fistula on an image that resembles the surgical view and can be used for the preoperative surgical planning.

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