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.


Labyrinthine fistulas are abnormal communications between the inner and middle ear compartments. Their clinical diagnosis is difficult, because typical clinical signs are not always present. 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. Although data on the size of the labyrinthine fistula are rarely available in the published series, 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. Surgical exploration is often necessary in cases of invalidating clinical signs without radiologic arguments. 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. 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. The data-processing algorithm that allows virtual endoscopy is currently available on many CT scan workstations. The threshold variation associated with this technique allows a reconstruction of the bony structures, depending on their density and thickness.
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 performed a high-resolution filter (Bone filter, 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.

The second protocol was a virtual endoscopy protocol. In this protocol, the postprocessing program enhanced the density resolution (same settings as for the axial view protocol, with a standard filter). A 3-D reconstruction of the labyrinth was obtained on the basis of 150 CT scan sections using a surface-
Table. Size of the Fistulas in the Temporal Bone Specimens

<table>
<thead>
<tr>
<th>Temporal Bone</th>
<th>Superior SCC</th>
<th>Lateral SCC</th>
<th>Posterior SCC</th>
<th>Promontory</th>
</tr>
</thead>
<tbody>
<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.

rendering built-in program (Advantage Navigator software; GE Healthcare, Chalfont St Giles, England). The promontory and the lateral, posterior, and superior semicircular canals were systematically explored after the 3-D reconstruction. The virtual endoscopic viewer was placed in the middle ear cavities, looking to the inner ear wall. The view axis was set perpendicular to the examined surface. The reconstruction threshold was gradually increased by increments of 1 Hounsfield unit (H). With an increase of the reconstruction threshold, an alteration of the 3-D image could be observed. Structures with densities below the reconstruction threshold disappeared from the 3-D reconstruction, and the lumen of the bony labyrinth could be gradually visualized. The threshold (in Hounsfield units) at which a localized virtual opening of the labyrinthine wall appeared was defined as the opening threshold (Figure 1). Independent measurements were performed on the same 3-D reconstruction and anatomical site after variation of the view angle. The opening thresholds before and after dissection or fistula creation were compared. The image at the opening threshold after dissection was compared with that obtained at the same threshold before dissection for each location to investigate false-positive images.

Opening thresholds before and after dissection were compared by a 1-way analysis of variance followed by a Dunnett multiple comparisons posttest. Values were expressed as the mean ± SEM of independent measurements. Statistical significance was considered to be P<.05.

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).

**Figure 4.** Virtual endoscopy of calibrated fistulas in temporal bones C, D, and E. Three-dimensional images were obtained from computed tomographic scan native axial views. The virtual endoscope was placed in the middle ear cavities, looking to the inner ear wall. To look for false-positive images, views of each fistula site before and after fistula creation were compared at the same threshold (866 Hounsfield units [H] for bone C, 1684 H for bone D, and 772 H for bone E), corresponding to the opening threshold after fistula creation. On the left (before fistula), no opening of the labyrinthine wall was observed. On the right (after fistula creation), fistulas are indicated by arrows. In temporal bone C, although both fistulas had a 0.5-mm diameter, the opening of the lateral semicircular canal (SCC 2) appeared larger than the one in the superior SCC (SCC 1) because of a thinner labyrinthine wall in this region. In temporal bone D, the promontory fistula was visualized as a notch on the inferior ridge of the oval window. In temporal bone E, the 0.3-mm fistula in the posterior SCC could be visualized without a false-positive image before fistula creation.

**Figure 5.** Virtual endoscopy of the lateral semicircular canal and the promontory of control temporal bone A. Three-dimensional images were obtained from computed tomographic scan native axial views. The virtual endoscope was placed in the middle ear cavities, looking to the inner ear wall. Comparative views before and after dissection were obtained at the same threshold (1229 Hounsfield units [H] for the lateral semicircular canal and 1684 H for the promontory), corresponding to the opening threshold after fistula creation. Similar virtual openings were obtained at the same locations.
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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