High-resolution Petrous Bone Imaging Using Multi-slice Computerized Tomography

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INTRODUCTION

Comprehensive assessment of the petrous bone requires high-resolution computerized tomography (HR CT) (1, 2). Multi-slice (MS) scanning, a recently introduced technology in CT, has been attributed a superior image quality compared to single-slice scanning due to an improved detail resolution along the patient’s z-axis and an increased scan velocity, which reduces motion-related artifacts (3–5). Thus, petrous bone assessment should potentially be enhanced by the use of multi-slice CT scanners.

Post-processing (PP) of HR cross-sectional data has been suggested as a useful tool for comprehensively visualizing the complex architecture of the petrous bone (2, 6–9). As the quality of reconstructed images depends crucially upon the resolution of the cross-sectional source data, MSCT data can be expected to yield reconstructions of superior image quality. Moreover, the two- to threefold increase in scan numbers with MSCT makes data PP an indispensable constituent of temporal bone assessment.

We defined a data acquisition protocol for high-resolution MSCT of the temporal bone and assessed its impact on data acquisition and PP.

MATERIALS AND METHODS

A cadaveric phantom was examined with an MS (34 detector rows, 4 slices) CT scanner (Aquilion, Toshiba, Japan) using different HR kernels (FC 80–89), slice thicknesses (0.5–1.0 mm) and reconstruction intervals (0.2–0.3 mm) as well as different tube currents (100–300 mA). The scan protocol providing adequate detail recognition, as assessed by delineation of the ossicular chain, with the lowest radiation exposure possible, according to the applied tube current, voltage and pitch factor was chosen. The following parameters defined the acquisition protocol of the helical scan: 120 kV, 100 mA, pitch factor 3.5, 0.5 mm slice thickness, 0.2 mm reconstruction interval, HR reconstruction algorithm (FC 81), 512 × 512 matrix, 160 mm field of view (FOV). Dosimetric measurements were performed using a head calibration phantom for evaluating the radiation exposure of the eye lenses. Thirty-eight patients with suspected middle ear disorders underwent MSCT scanning. All patients used a lens shield (AttenuRad; F&L Medical Products Co, USA). All scans were post-processed to generate 2D reformations and 3D reconstructions of the tympanic cavity, using the volume-rendering technique (VRT). Additionally, a total of 17 petrous bone scans (120 kV, 170 mA, 1 mm slice thickness, 160 mm FOV) from patients with clinically suspected middle ear disorders, performed in an incremental scanner (Somatom Plus; Siemens, Germany), were retrospectively postprocessed using the same protocol.

The parameters image quality and diagnostic value of the cross-sectional source images and related 2D reformations and 3D reconstructions were assessed for MSCT and incremental CT and scored (1 = insufficient to 5 = excellent) by three radiologists with
different degrees of neuroradiologic training. Statistical evaluation was effected by the use of a two-sided t-test for unpaired samples.

In order to compare single- and multi-slice helical scan techniques with respect to image quality of 3D reconstructions, a cadaveric temporal bone phantom for surgical training purposes, embedded in plaster, was examined by MSCT as well as single-slice HR scanning (1.5 mm slice thickness, 0.5 mm reconstruction interval).

Other PP techniques, i.e. surface rendering and a combination of surface and volume rendering, known as hybrid rendering, were applied to MSCT data in selected cases.

RESULTS

Image quality in MSCT scanning within the selected range of variation was most significantly affected by the choice of the HR reconstruction algorithm, whereas the reconstruction interval and the tube current only affected the HR image to a minor degree (Figs. 1 and 2). The use of a FOV of 160 mm, a 512 × 512 matrix and a reconstruction interval of 0.2 mm resulted in a voxel size of ≈ 0.3 × 0.3 × 0.35 mm³.

The data acquisition protocol yielded HR images with an excellent detail resolution, permitting assessment of the stapes suprastructure and the bony outer lamella of the tympanic portion of the facial canal on a regular basis (Fig. 3). Cross-sectional MSCT scans and their orthogonal reformations as well as volume-rendered 3D reconstructions yielded a significant increase in image quality and diagnostic value (p < 0.001, t-test) compared to incremental CT scans (Table I). Visual assessment of the volume-rendered cadaveric phantom in plaster also showed a superior image quality of MSCT-based reconstructions as compared to single-slice helical CT (Fig. 4).

Radiation exposure to the lenses amounted to 15 mGy with the lens shield in place. The use of the lens shield reduced radiation by 40% without producing any artifacts which significantly affected the image quality.

**Fig. 1.** Axial MSCT scans of a cadaveric phantom using different HR kernels: (a) FC 80, (b) FC 81, (c) FC 82. Kernel FC 81 provides the best image quality in terms of detail resolution.

**Fig. 2.** Axial MSCT scans of a cadaveric phantom using different tube currents in the following order: (a) 200, (b) 150 and (c) 100 mA. No significant alterations in terms of detail and/or contrast resolution are seen.
quality of the source data and/or reconstructed images. VR of the MSCT data yielded extra- and endoluminal 3D views of the temporal bone with excellent detail recognition (Fig. 5a, b). Threshold-based surface rendering and additional segmentation procedures provided integrative imaging models of middle and/or inner ear structures within the semitransparent petrous bone (Fig. 5c). Hybrid rendering allowed for visualization of implant material such as cochlea implant electrodes and tube conductors in relation to surrounding anatomic structures (Fig. 5d).

DISCUSSION

The aim of the present study was to establish and assess a data acquisition protocol for HR petrous bone scanning using MSCT technology. MSCT accelerates data acquisition while at the same time yielding a higher spatial resolution. The quality of cross-sectional source images as well as of 2D and 3D reconstructions is improved due to a reduction in partial volume and motion-related artifacts and as a result of optimized reconstruction algorithms (3, 5, 9). The higher spatial resolution along the z-axis of the pa-
tient provides an almost isotropic voxel size. This is especially important for petrous bone imaging as it is very difficult to assess the complex internal architecture without using reformatted and/or reconstructed images (2, 6). Owing to the differences in detector configuration, tube rotation time and reconstruction algorithm, it is not possible to transcribe established single-slice helical scan protocols for MSCT data acquisition. For this reason, we used a human cadaveric phantom, which was repeatedly scanned in order to define a scan protocol that takes full advantage of the inherent qualities of MS scanning while at the same time reducing the radiation dose to the minimum level required for adequate image quality. In contrast to incremental and single-slice helical scans, gantry angulation is not yet possible with MSCT helical scanning, thus increasing the radiation exposure of the eye lenses. The petrous bone, being a high-contrast object, permits the use of a low tube current. Together with the short tube rotation time of 0.5 s/rotation, the product of tube current and rotation time may be reduced to a value as low as 50 mA s. Additionally, the use of a non-lead lens shield, which causes only minor image artifacts, reduces the lens radiation dose by 40% to 15 mGy in the case of the head calibration phantom. This dose is higher than that reported for supraorbitomeatal baseline scans (10–12); however, the exposure is reduced by a factor of about three compared to petrous bone scans in the transverse plane (10–12). A further reduction in radiation exposure can be achieved by reining the patient’s head.

Practical improvements of the higher spatial resolution of MSCT result in visualization of the stapes suprastructure (Fig. 3a) and of the bony outer lamella of the tympanic portion of the facial canal (Fig. 3b). The need for bilateral retrospective data processing with a smaller FOV (6) as well as sequential coronal and axial scanning (2) for emphasizing bony details is obviated by MSCT. The faster image acquisition with the MSCT scanner that results from the simultaneous acquisition of four slices reduces motion-related artifacts that may be especially disadvantageous when image reformation or 3D reconstruction is considered. Furthermore, patients whose capacity to cooperate is limited, such as children and

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Fig. 5. Different PP techniques based on MSCT data. (a, b) Volume-rendered views of the temporal bone: (a) temporal bone fracture extending into the external acoustic canal (EAC); (b) lateral view of the tympanic cavity. (c) Surface-rendered view of both petrous bones with the segmented and color-coded labyrinth in place. (d) Hybrid rendering, showing status post-bilateral cochlea implant surgery; the course and site of the implant electrodes are visualized.
injured individuals, may undergo petrous bone scanning without the need for sedation due to the short examination time (≈ 13–15 s).

Image reformation and/or reconstruction is indispensable not only because of the complex inner architecture of the petrous bone but also because the number of scans is increased by a factor of two to three. Thus, sequential image analysis is very time-consuming and photographic documentation of all scans may not be possible for economic reasons.

The two other PP techniques selectively applied to MSCT data in this study, i.e. surface rendering and hybrid rendering, also yielded an excellent detail representation in all reconstructions (Fig. 5c,d).

CONCLUSIONS

The higher spatial resolution and increased scan speed provided by HR MSCT reduce partial volume effects and motion-related artifacts. This technique ensures an adequate visualization of important pathoanatomic details, such as the stapes superstructure, allows for imaging of uncooperative patients and obviates the need for retrospective data processing and multiplanar scanning. Common image PP techniques are enhanced by MSCT scanning. PP itself is becoming more and more important in order to cope with the considerably increased number of scans obtained. The manufacturers need to further develop their technology in order to provide scanners that enable helical scanning with tube angulation, thus reducing lens radiation exposure.

REFERENCES


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