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Comparison of volumetric reconstructions obtained from CT and micro-CT scans of the petrous bone

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Abstract: This study presents effects of volumetric reconstructions of the petrous bone anatomy obtained from image data delivered by the medical CT scanner (Optima CT 660) and micro-CT scanner (Nanotom 180N) used in biological and technical applications. Although most of the osseous structures of the ear were visible in the subsequent serial CT scans delivered by the computed tomography system (Optima CT 660), their composition into volume was not satisfactory for viewing as a three-dimensional reconstruction. Micro-CT imaging of the anatomical structures of the petrous bone performed by the Nanotom 180N device was considerably superior to the medical computed tomography and the reconstructed anatomical structures presented a high level of accuracy and very realistic appearance.

Key words: temporal bone, computed tomography, micro-tomography.

Introduction

Computed tomography provides cross-sectional views of the interior of the human body or of selected organs. CT scans and volumetric reconstructions obtained from CT data are useful for clarifying anatomical relationships and identifying pathological changes within the human body. Both 2D and 3D images are necessary for depicting morphology and topography of the internal organs [1–3]. The detection and appropriate recognition of dysmorphologies, particularly on the micro-scale, are essential in order to take rapid steps aimed at treating disease or performing surgical intervention. For many years the temporal bone has been a subject of numerous and various morphological analyses [4–9]. Admittedly, it was dictated by the fact that this bone houses the organ of hearing encapsulated in its bony matrix. The small size of the ear components force application of high resolution imaging techniques for accurate depiction of their anatomy. In clinical examination, high resolution images are delivered by computed tomography whose spatial resolution can be below 1 mm [10]. Nevertheless, such image resolution can not compare to resolution obtained by contemporary micro-CT scanners which can deliver images with pixel size on the order of micrometers.

The aim of this study was to compare the effects of volumetric reconstructions of the ear structures obtained from medical CT scanner and micro-CT scanner used in biological and technical applications. In this study we focused on presenting 3D reconstructions of the petrous part of the temporal bone and the osseous structures associated with the outer, middle and inner ear.

Material and methods

To visualize inner structures of the ear we harvested the temporal bones from two different human skulls of adult individuals of the male and female sex. Further, the petrous parts were dissected and subjected separately to the computed tomography system (Optima CT 660) used for diagnostic purpose in clinical examination of humans, and to computed micro-tomography (Nanotom 180N device produced by GE Sensing & Inspection Technologies Phoenix X-ray Gmbh) which is a high-resolution microfocus X-ray system dedicated for scientific and industrial computed tomography. The tomograms were registered on a Hamamatsu 2300×2300 pixel detector and reconstructions of measured bone samples were done using GE software datosX ver. 2.1.0 with Feldkamp algorithm [11].

For Optima CT examination the following parameters were used: DFOV = 25.2 cm, slice thickness = 0.625 mm, kV = 140, mA = 100. In turn, the applied nano-CT system provided ultra high spatial and contrast resolution allowing reconstruction of objects with voxel size of 19 μm. The X-ray tube parameters were set to: 70 kV and 250 μA.

Analyzed temporal bones were of normal anatomy and did not reveal any traces of bone tissue deterioration which could have resulted from inflammatory processes or from postmortem decomposition of bone tissue. Although the studied material is limited to few samples it is enough to detect potential similarities and dissimilarities in anatomical details visualized by the micro-CT and clinical CT scanners. Two-dimensional and three-dimensional imaging of the anatomical structures of the ear was based on multiplanar reconstructions and volume rendering of the CT and micro-CT data.

To obtain three-dimensional reconstructions of the petrous bone and its internal structures the CT and micro-CT scans were processed with the CTVox volume rendering software (SkyScan company http://bruker-microct.com/products/downloads.htm).

Results

The micro-CT scanner used for evaluation of the anatomy of the petrous bone revealed structural details with accuracy comparable to microscopic examination. Detailed anatomical features having the form of the spikes, depressions or apertures a few millimeters or less in size were well visible in 3D reconstructions, precisely showing the morphological features of the ear.

Conversely, the computed tomography system Optima CT 660 used for clinical examination of the petrous bone was not able to capture all anatomical details of the middle and inner ear and their appearance in the volumetric reconstructions was not satisfactory for detailed anatomical studies. However, singular serial CT scans presented anatomical details of the ear better than volumetric reconstructions. Thereby, medical tomography is not as good as micro-CT as an imaging modality for creating accurate and realistic 3D models of the ear structures. Comparison of the petrous part of the temporal bone rendered from data obtained from the medical tomograph (Optima CT 660) and the micro-tomograph (Nanotom 180N) is shown in Fig. 1. It is apparent that there are no significant differences in the appearance of the surface anatomy of the petrous part of the temporal bone visualized from CT and micro-CT data. Nevertheless, close-up view reveals higher noise in the image obtained from CT scans and composed into volume, resulting in the anatomical details being blured. This is visible particularly when internal anatomy of the petrous bone is examined by computed tomography. In this case, volumetric reconstructions obtained from micro-CT scans presents a high quality of anatomical detail imaging (Fig. 2).

In the cross-sections through the petrous bone visualized by medical CT and micro-CT, the same anatomical details were visible (e.g.: external auditory canal, carotid canal, cochlea, oval window). However, with increasing image magnification, they were no longer sharply visible on the reconstructions created from medical CT

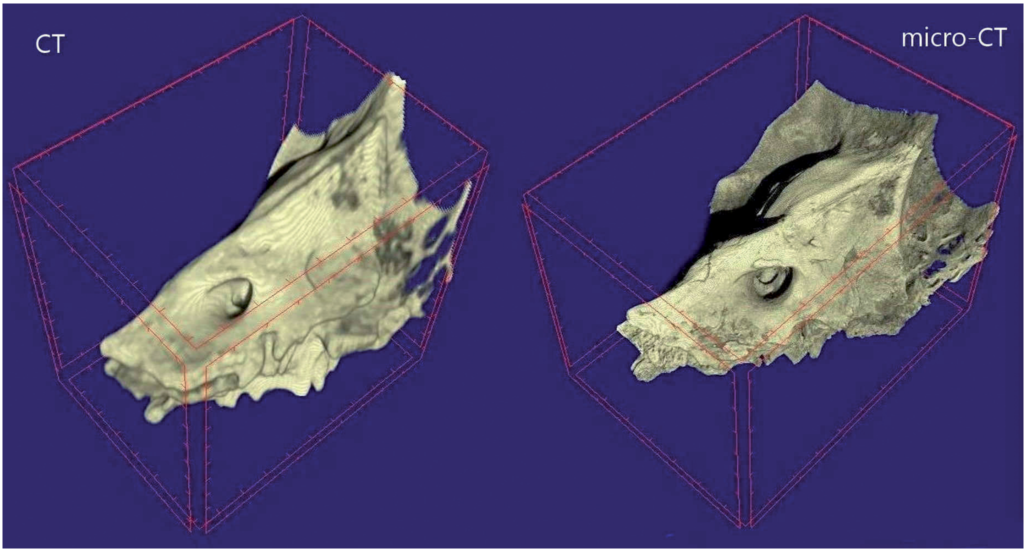

Fig. 1. Volumetric reconstruction of the petrous part of the temporal bone obtained from CT data and micro-CT data. The surface of the petrous bone reveals the same anatomical details captured by both imaging modalities.

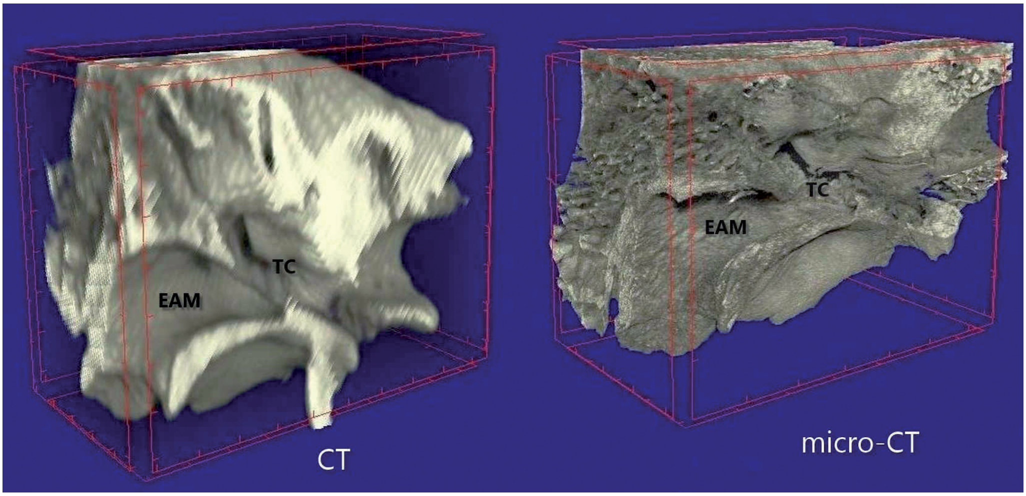

Fig. 2. The cross-section through the external acoustic meatus (EAM) and the tympanic cavity (TC) visualized by volume rendering in medical computed tomography and micro-tomography. A considerable difference in image quality of the reconstructed region of interest is well visible.

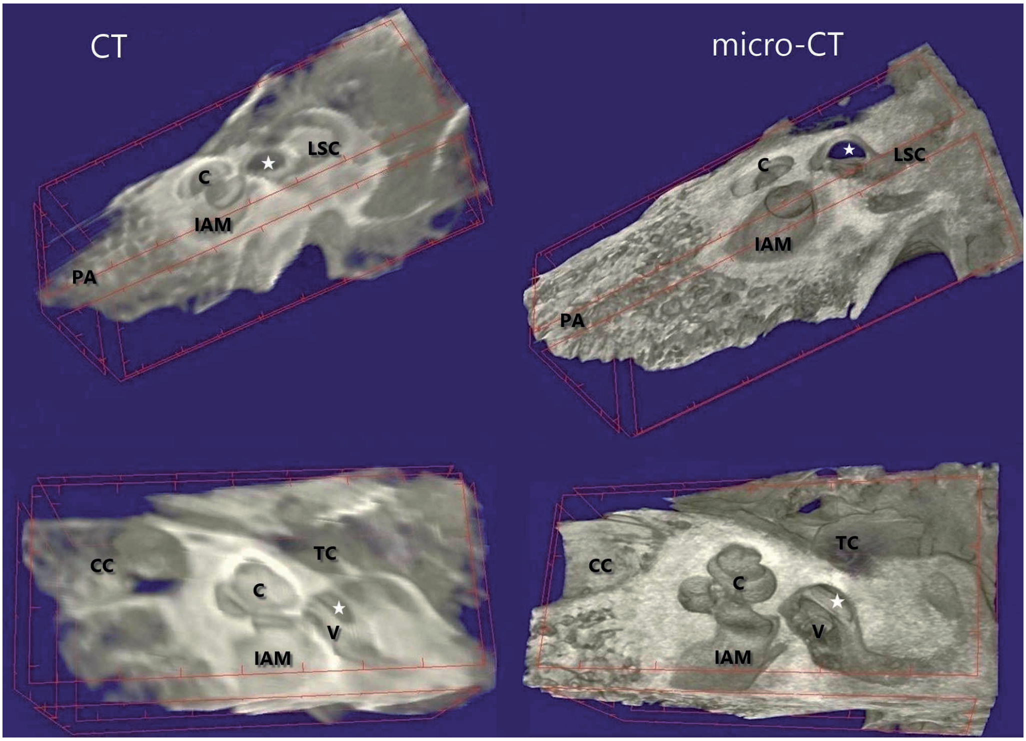

Fig. 3. Cross-sections through the petrous bone showing selected structures of the middle and inner ear rendered from CT and micro-CT data; PA — petrous apex, CC — carotid canal, C — cochlea, IAM — internal acoustic meatus, TC — tympanic cavity, V — vestibule, LSC — lateral semicircular canal.

data. Hence, in the case of medical computed tomography volumetric reconstruction revealed artifacts (oblique stripes in the image), whereas the same sample examined by micro-CT delivered artifact-free visualization of the anatomical structures. Anatomical details of the petrous bone which measured 1 mm or less in size were detected by medical tomography but the quality of images differed significantly from images rendered from micro-CT data. The example of discrepancies in image quality of these two modalities is presented by the volume rendering of the cochlea and surrounding structures obtained from the medical CT and mico-CT data presented in Fig. 3.

Discussion

Computed tomography has become a routine method used for imaging the temporal bone and ear structures in clinical examination. Although magnetic resonance imaging can supplement CT findings and enhance diagnoses of ear diseases, computed micro-tomography opens completely new perspectives for imaging internal anatomy of the temporal bone and ear structures [12–14]. Originally, this imaging method was dedicated for evaluation of bone architecture, but its further development enabled visualization of soft tissues, even when they are unstained [15]. Thereby, computed micro-tomography appears as the ideal solution for multimodal imaging of the ear structures built from osseous and soft tissues.

The human ear contains both large- and small-scale structures, and therefore not all anatomical details can be shown in clinical imaging with the aid of computed tomography or magnetic resonance. Ahuja *et al.* depicted anatomical structures of the temporal bone using high-resolution computed tomography [16]. In turn, Dahmani-Causse *et al.* used cone beam computed tomography for morphologic examination of the temporal bone and compared their results to multislice helical computed tomography. They found that there was no significant difference in morphologic assessment of the temporal bones on the two techniques, though the CBCT characterized higher spatial resolution than on MSCT [17]. Peltonen *et al.* also stated that cone-beam CT is a promising method for otologic imaging thanks to its accuracy and relatively low radiation exposure per investigation [18].

Micro-CT scanners can deliver many more serial slices of the temporal bone than clinical CT scanners. Therefore, the quality of volumetric reconstructions obtained from micro-CT data will be much better than in the case of standard medical tomography. This property allows the creation of realistic 3D reconstructions and printable 3D models, particularly in the case of small anatomical structures. Reisser *et al.* used a volumetric-rendering algorithm to depict image data from high-resolution helical CT showing the osseous structures of the human ear. Using this method they were able to demonstrate the following anatomic structures: internal auditory canal, cochlea, vestibule, semicircular canals, distal part of the vestibular aqueduct, complete ossicular chain, fallopian canal and internal carotid canal. However, they had difficulties finding the three-dimensional delineation between the complete vestibular and cochlear aqueduct, as well as the modiolus [19].

Three-dimensional imaging influences the perception of the observer much better than 2D images. This is important for understanding ear anatomy because many of its components have complex geometry and are organized in multiplanar fashion [20].

The amount of visual information presented, particularly in computed micro-tomography, is immense and usually requires computers to have a quick processor, a high quality graphics card and high-speed computing software. The micro-CT scanners deliver much more data than CT-scanners used for clinical examination. For comparison, in our micro-CT study of the petrous bone yielded 900 files, whereas the same sample subjected to the medical CT was captured in 180 files. Also, the size of each individual file (one CT-scan) delivered by micro-CT is considerably larger than a file obtained using the DICOM standard widely used in medical computed tomography (e.g.: 8 MB versus 516 KB). All these technical conditions are essential for efficient and satisfactory visualization of large data sets obtained from the CT-scanner and should be considered prior to evaluation of the morphological features of the temporal bone, particularly its petrous part.

The weakness of micro-tomography includes the fact that this imaging modality cannot be applied in medical examination of large parts of the human body because of physical obstacles, which makes this technique a valuable tool for preclinical studies. Up until now, micro-tomography has been used mostly for laboratory research and has served occasionally for verifying clinical results obtained from extracted biological material. Therefore, the computed tomography is still regarded as a satisfactory tool for diagnosing ear diseases by imaging morphological alterations and as an aid to surgical planning [21–23]. Nevertheless, for anatomical studies, images obtained from micro-tomography appear more accurate and are comparable to images observed via endoscope or operating microscope. Micro-tomography allows not only the capture of surface details but it can also look inside the structures with ultra-high resolution, which makes it definitely superior over any other clinical imaging modality used for investigation of the temporal bone anatomy and focused on depicting the ear structures.

Conclusions

The micro-computed tomography enhances investigation of the complex anatomy of the petrous bone, and helps to understand the spatial relationships between the internal structures composing the middle and inner ear. Volume and surface reconstructions obtained from micro-CT data are very realistic and influence much better the perception of the observer than visual effects obtained from medical tomography, particularly in morphological evaluation of the anatomical details of the middle and inner ear.

Conflict of interest

None declared.

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