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ScienceDirect
Journal of Otology xx (2017) 1–9
www.journals.elsevier.com/journal-of-otology/

Clinically relevant human temporal bone measurements using novel high-resolution cone-beam CT

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Received 16 December 2016; revised 12 January 2017; accepted 16 January 2017

Abstract

Objective: To test the feasibility of measuring fine temporal bone structures using a newly established cone-beam computed tomography (CBCT) system.
Materials and methods: Six formalin-fixed human cadaver temporal bones were imaged using a high-resolution CBCT system that has 900 frames and copper + aluminum filtration. Fine temporal bone structures, including those of the facial nerve canal and vestibular structures, were identified and measured.
Results: The fine structures of the middle ear, including the tympanic membrane, tendon of the tensor tympani, cochleariform process of the semicanal of the tensor tympani, pyramidal eminence, footplate of the stapes, full path of the facial nerve within the temporal bone, supra-labyrinthine space, semicircular canals, pathway of the subarcuate canal, and full path of the vestibular aqueduct, were clearly demonstrated. The vestibular aqueduct has a midpoint width of 0.4 ± 0.0 mm and opercular width of 0.5 ± 0.1 mm (mean ± SD). The length of the internal acoustic meatus was 10.6 ± 1.2 mm (mean ± SD), and the diameter of the internal acoustic meatus was 3.7 ± 0.3 mm (mean ± SD).
Conclusion: This novel high-resolution CBCT system has potentially broad applications in the diagnosis of inner ear disease and in monitoring associated pathological changes, surgical planning, navigation for the ear surgery, and temporal bone training.
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Keywords: CT; Temporal bone anatomy; Vestibule; Facial nerve

1. Background

Superior to multi-detector computed tomography (MDCT), cone-beam CT (CBCT) has fast data acquisition (less than a minute versus several minutes for MDCT), low-dose exposure of the subject, smaller floor area footprint of the imaging apparatus, a relatively low equipment purchase price, and has broad applications in head and neck imaging (Stutzki et al., 2015). The excellence of CBCT in temporal bone imaging has been demonstrated including visualization of the intra-scalar positions of cochlear implant electrodes and facial nerve canal measurements and potential diagnosing semi-circular canal dehiscence (Eibenberger et al., 2014; Husstedt et al., 2002; Komori et al., 2013; Pearl et al., 2014; Verbist et al., 2005; Zou et al., 2015b). Even a prototype system for intraoperative CBCT imaging has been developed to track the drill during temporal bone surgery (Erovic et al., 2013).

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Peer review under responsibility of PLA General Hospital Department of Otolaryngology Head and Neck Surgery.

http://dx.doi.org/10.1016/j.joto.2017.01.002
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Please cite this article in press as: Zou, J., et al., Clinically relevant human temporal bone measurements using novel high-resolution cone-beam CT, Journal of Otology (2017), http://dx.doi.org/10.1016/j.joto.2017.01.002

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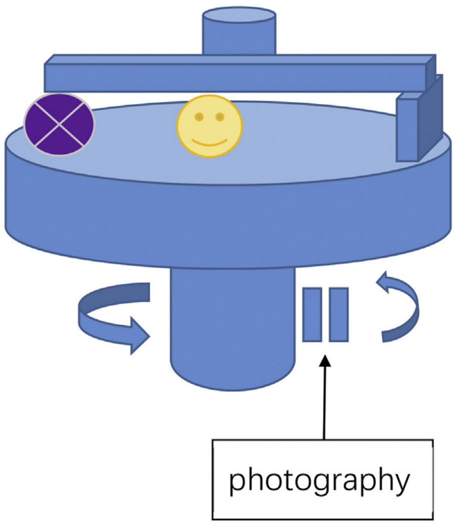

Fig. 1. Illustration of the novel CBCT system. The system is composed of an imaging part on the top and a mechanic plateform at the bottom. The spaceman was placed on the plateform that rotates. A pause (||) was included in the rotation during each exposure for photography.

For both diagnosing the middle and inner ear diseases and intraoperative tracking of the drill during temporal bone surgery, it is necessary to obtain images with high spatial resolution. Bremke et al. reported visualization of experimental superior semicircular canal dehiscence (SSCD) using a CBCT with voxel resolution (section thickness) of 0.125 mm (Bremke et al., 2015). Although CBCT was significantly better than MDCT in identifying a thin bony coverage of a superior semicircular canal (SSC), the reliability of the radiological findings does not legitimate the diagnosis of an SSCD based on radiologic data alone due to existence of false-positive results. There is still a room to improve the resolution of CBCT. We recently designed a novel high-resolution CBCT acquisition system with voxel size of 0.1 mm that involves a pause during each of the exposures of the multiple frames (Fig. 1) (Zou et al., 2015a). The new CBCT system provided a chance to improve the accuracy of diagnosis and intraoperative tracking of the drill. Aimed to test the feasibility in clinical use, we analyzed the critical temporal bone structures, including the vestibular aqueduct, the semicircular canal wall, the facial

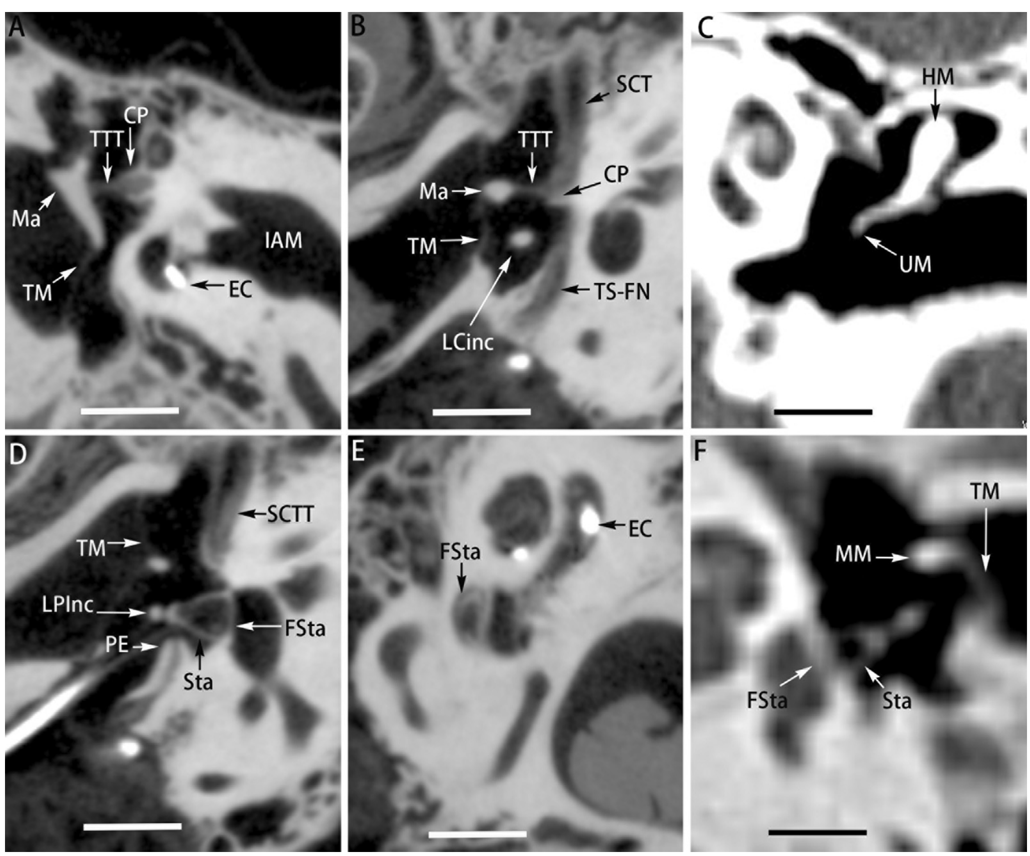

Fig. 2. Middle ear structures of the temporal bone demonstrated by a novel high-resolution CBCT system in comparison to the conventional MDCT. In CBCT, a total of 900 cone-beam projections were acquired by rotating the specimen (left side A, B, and D; right side E) around axial axis and the target structures were identified by adjusting the location and orientation of the axial, sagittal and coronal viewing planes. In MDCT, the isotropic volumes of entire temporal bone including both sides were acquired on axial orientation. The target structures were displayed by adjusting the location and orientation of the axial, sagittal and coronal viewing planes of the selected the left side (C, F). CP: cochleariform process; EC: electrode contact; EEC: external ear canal; Sta: stapes; FSta: footplate of the stapes; HM; head of malleus; IAM: internal auditory meatus; Ma: malleus; MM: manubrium of malleus; TTT: tendon of the tensor tympani; SCTT: semicanal of the tensor tympani; LPInc: lenticular process of the incus; LCInc: long crus of the incus; PE: pyramidal eminence; TM: tympanic membrane; TS-FN: tympanic segment of the facial nerve; UM: umbo of malleus. Scale bar = 5 mm.

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