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ORIGINAL ARTICLE

Morphologic examination of the temporal bone by cone beam computed tomography: Comparison with multislice helical computed tomography

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Summary
Introduction: High-resolution CT imaging is essential to diagnosis and follow-up of temporal bone pathology. Morphologically, CT is the reference examination. The requirement of long-term follow-up thus exposes patients to cumulative radiation doses. Limiting exposure to ionizing radiation is an increasing concern of public health authorities. The principal advantage of Cone Beam CT (CBCT) lies in a significant reduction in radiation dose. The main objective of the present study was to assess the morphologic concordance between CBCT and Multislice Helical Computed Tomography (MSCT) on 20 anatomic landmarks corresponding to regions of interest in clinical practice. The secondary objectives were to compare the two techniques qualitatively in stapes and footplate assessment and measurement of footplate thickness, and quantitatively in terms of dosimetry.
Material and methods: An experimental anatomical study was performed on 12 temporal bones from fresh human cadavers of unknown clinical history. Each underwent CBCT and MSCT.
Results: There was no significant difference in morphologic assessment of the temporal bones on the two techniques. Exploration of the stapes, incudostapedial joint, anterior stapediovestibular joint and footplate was qualitatively more precise on CBCT, and footplate thickness showed less overestimation than on MSCT. CBCT delivered 22 times less radiation than MSCT under the present experimental conditions.
Conclusion: CBCT provides reliable morphologic assessment of temporal bone, thanks to higher spatial resolution than on MSCT, with significantly reduced radiation dose.

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Introduction

Technological advances in radiology over the last 30 years have significantly changed the role of imaging in both diagnosis and postoperative follow-up of otologic and otoneurologic pathology. Morphologically, CT is the reference examination.

Cone-beam X-ray systems, used in dentistry, allow significantly lower radiation doses than classical CT.

Limiting radiation-linked health risk is a growing issue in public health, as can be seen from the EU Euratom Directives 96/29 and 97/43, which stress two fundamental principles:

- a principle of justification, the prime principle of protection of patients exposed to ionizing radiation: the clinical indication for and choice of imaging technique and the necessity of the examination in risk/benefit terms require justification;
- a principle of optimization: ionizing radiation exposure is to be ''as low as reasonably achievable'' (the ''ALARA'' principle) for a given result.

Cone beam CT (CBCT) meets this objective of minimized radiation; its technical performance and reliability in the case of temporal bone imaging, however, remain insufficiently documented.

Technical description

CBCT is at present not priced as a budget-item in the French health system, although the machines are CE-labelled, and is therefore not used in French public-sector hospitals. The French Radiology Society (Société Française de Radiologie) recently asked the Health Authority to recognize and price this examination, and an evaluation report published in December 2009 highlighted its feasibility for temporal bone imaging while adding that ''further studies are needed to confirm these preliminary findings and determine the potential benefits of cone beam as compared to other imaging techniques'' [1].

The devices first developed in the 1990s were dedicated to implantology and dental imaging, but applications are now spreading to the face and skull base as a whole.

Present-day machines differ widely in their capacities. Temporal bone exploration requires optimal power and resolution.

Cone Beam volume tomography is based on a different principle to classical CT. The X-ray beam is open and conical, allowing projection imaging. In most cases, the beam is pulsed, rather than continuous as in classical scanners.

CBCT performs a finite number of conical projections, processed by digital detectors, under different successive angles of view around the target. At end of rotation, a large number of digitized plane images are distributed according to the circular rotation path of the system. The digital data of the multi-angle projections are processed by algorithms that reconstruct the volume of the target according to its voxels. The open beam scans the entire target region in a single revolution.

2D or 3D reconstructions are acquired from the digitized volume. As in classic CT, 2D reconstructions may be axial, panoramic (in the case of wide-field models) or transaxial (vertical and transversal), in real size [2].

The CBCT concept lies between those of conventional X-ray and multislice CT (MSCT) and seems especially suited for high-density structures. Its spatial resolution is much better than MSCT. Voxel size is isotropic, between 125 and 75 microns in secondary reconstruction. This can compensate for poorer density resolution, providing sufficient contrast between temporal bone structures, air and soft tissue [3,4].

The principal objective of the present study was to assess morphologic concordance between CBCT and MSCT in temporal bone imaging. The secondary objectives were to compare the two techniques in terms of quality of assessment of the footplate region and of radiation dose.

Materiel and methods

Twelve fresh human cadaver hemi-heads of unknown clinical history were provided by the anatomy laboratory of our ENT department.

All temporal bone specimens underwent CBCT and MSCT imaging on the same machines, using the same protocols, in a single session, in the radiology unit. All acquisitions were thus unilateral.

Cone Beam CT (CBCT)

The system was a vertical NewTom VGI (NewTom, Verona, Italy).

The hemi-heads were immobilized in the apparatus by polystyrene plaques, in the position of the head of a seated person. A high-resolution protocol was implemented.

The system used a 200×25 mm flat-panel detector at 650 mm from the radiation source. The 360° rotation of the X-ray tube took 18 sec. Tube voltage was 110 kV, with 19 mA charge at the terminals. Total filtration was 2 mm and pitch 125 μ, with field of view (FOV) corresponding to a 12* 7.5 cm diameter cylinder.

Acquisition began with frontal and lateral location of the temporal bone region of interest. Acquisition time was 18 sec.

Images were reconstructed in 125 μ isometric voxels, enabling 3D reconstruction without loss of resolution.

Multislice Helical Computed Tomography (MSCT)

The scanner was a Philips helicoid 40-channel device. The high-resolution protocol used only two channels, in 0.5 mm collimation. Tube voltage was 140 kV, charge 300 and 350 mA, pitch 0.37, and field of view (FOV) 160 mm, with a 30 mm helix. Rotation time was 0.115 sec and acquisition time 65 sec. A hard filter was used.

Reconstruction was implemented every 0.55 mm of thickness with 0.1 mm increment.

The hemi-heads were immobilized in the position of the head of a person in dorsal decubitus.

Image analysis

After acquisition, the MSCT and CBCT images were digitized and recorded and saved on their respective systems.

The primary objective was to assess anatomic concordance between the two imaging techniques. Twenty anatomic landmarks were selected, corresponding to middle and inner ear regions of interest in clinical practice:

- middle ear: epitympanic recess, tegmen tympani, sinus tympani, facial recess, facial canal, cochleariform process, incudomalleal joint, incudostapedial joint, long process of the incus, crura of the stapes, head of the stapes, footplate;
- inner ear: fissula ante fenestram, modiolus, cochlear partition, round window, otic capsule homogeneity, semicircular canals, cochlear and vestibular aqueduct.

Each landmark was assessed by an ENT and a neuroradiology specialist on each imaging technique on the respective console, attributing a value of 1 if the anatomic structure in question could be ''identified'' and of 0 if ''non-identified''. Blinding was inapplicable, inasmuch as MSCT and CBCT images are easily recognizable as such by any observer. The 24 images were, however, analyzed in disorder so that, in a given temporal bone specimen, the examination of one would not influence the other.

There were several secondary objectives:

- comparison of precision of morphologic assessment of the stapes, footplate and incudostapedial and anterior and posterior stapediovestibular joints on MSCT and CBCT. Stapes and footplate reconstructions, perpendicular to the footplate and in the plane of the two crura of the stapes, were performed on the console by an experienced neuroradiologist. Image quality was graded 1 to 3 (1 = dubious; 2 = visible; 3 = well-defined) on the console by the same observer for the 2 techniques, for the following landmarks: anterior footplate thickness, posterior footplate thickness, anterior and posterior stapediovestibular joints, anterior stapes crus insertion, posterior stapes crus insertion, anterior crus aspect, posterior crus aspect, head of the stapes, and incudostapedial joint. Means, medians and standard deviations were compared by matched Wilcoxon t-test on Stata /SE 11.1 software;
- comparison of footplate thickness on MSCT and CBCT. Anterior and posterior footplate thickness was measured on console, using the graphic tool, to the nearest tenth of a millimeter in each temporal bone specimen. Means, medians and standard deviations were compared by matched Wilcoxon t-test on Stata /SE 11.1 software;
- dosimetric comparison, in milliGrays, based on the Computed Tomography Dose Index (CTDI), provided automatically by the MSCT and CBCT scanners.

Results

Principal objective

All middle and inner ear structures were identified on both techniques, with confidence intervals ranging from 73 to 100%.

Some anatomic particularities were found: stapediovestibular dislocation in temporal bone specimen 1 (Fig. 1); pericochlear hypodensity in specimen 4; peristapedial hypodensity in specimen 2; and lateral semicircular canal dysplasia in specimen 5. All were identified on both MSCT and CBCT. Specimens 3, 5, 6 and 7 showed fracture, described identically on both techniques.

Secondary objectives

Stapes/footplate

Mean grades were higher on CBCT than on MSCT (Table 1). The difference was statistically significant for six of the 10 structures assessed: anterior and posterior footplate thickness, stapediovestibular joint, posterior stapes crus insertion, head of the stapes, and incudostapedial joint.

Stapes crus insertion is to be graded ''well-defined'' when the absence of detachment or thickening is clearly visible [5]. Anterior crus insertion was well-defined according to both techniques, with no significant difference. Posterior crus insertion was graded well-defined in five out of 12 cases on MSCT and in 10/12 on CBCT.

Stapes crus aspect was well-defined according to both techniques, with no significant difference.

Anterior and posterior footplate thickness

Mean anterior footplate thickness was 0.45 mm on MSCT and 0.33 mm on CBCT ($P = 0.025$) (Table 2).

Mean posterior thickness was 0.54 mm and 0.35 mm, respectively ($P = 0.040$).

All thickness values, except for one anterior thickness measurement, were greater on MSCT than on CBCT. In all temporal bone specimens, footplate edges seemed better defined on CBCT than on MSCT, enabling more reliable thickness assessment; on MSCT, the edges were often fuzzy, and thickness assessment more approximate (Fig. 2).

Theoretic footplate thickness on histological cross-section is 0.3 mm [6]: CBCT values were closer to the theoretic histologic value.

Moreover, MSCT is known to tend to overestimate footplate thickness, which is therefore counted as normal up to 0.7 mm [5]. CBCT provides clearer assessment of the footplate edges, and thus more reliable measurement, with less overestimation of thickness.

Dosimetry

The automatic CTDI was noted at each examination (Table 3), and mean values were calculated for MSCT and CBCT. The radiation dose associated with CBCT acquisition was, on average, 22 times lower than for MSCT.

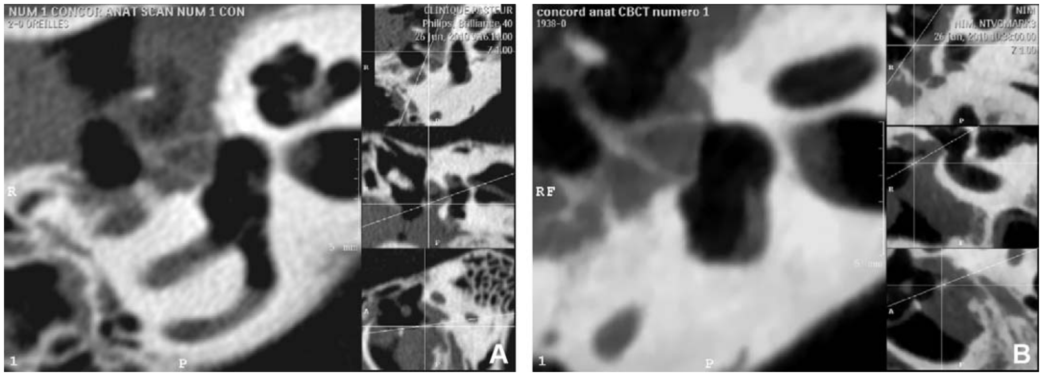

Figure 1 Temporal bone no. 1: anterior stapediovestibular dislocation on MSCT (A) and CBCT (B).

Table 1 Means, medians and standard deviations of grades 1—3 on 10 structures assessing the footplate region (1 = dubious; 2 = visible; 3 = well-defined).

Structure	MSCT			CBCT			*P*
	Mean	Median	SD	Mean	Median	SD	
Anterior footplate thickness	2.08	2.00	0.67	2.75	3.00	0.45	0.009
Posterior footplate thickness	1.91	2.00	0.70	2.73	3.00	0.65	0.009
Anterior stapediovestibular joint	1.92	2.00	0.79	2.50	3.00	0.67	0.015
Posterior stapediovestibular joint	1.25	1.00	0.62	1.58	1.00	0.79	0.084
Anterior stapes crus insertion	2.75	3.00	0.45	2.92	3.00	0.29	0.157
Posterior stapes crus insertion	2.33	2.00	0.65	2.83	3.00	0.39	0.026
Anterior stapes crus aspect	2.75	3.00	0.45	3.00	3.00	0.00	0.083
Posterior stapes crus aspect	2.83	3.00	0.39	3.00	3.00	0.00	0.157
Head of the stapes	2.58	3.00	0.51	3.00	3.00	0.00	0.025
Incudostapedial joint	2.00	2.00	0.74	2.92	3.00	0.29	0.006

Table 2 Anterior and posterior footplate thickness on MSCT and CBCT.

Structure	MSCT			CBCT			*P*†
	Mean	Median	SD	Mean	Median	SD	
Anterior footplate thickness	0.45	0.40	0.09	0.33	0.30	0.14	0.025
Posterior footplate thickness	0.54	0.50	0.21	0.35	0.30	0.14	0.040

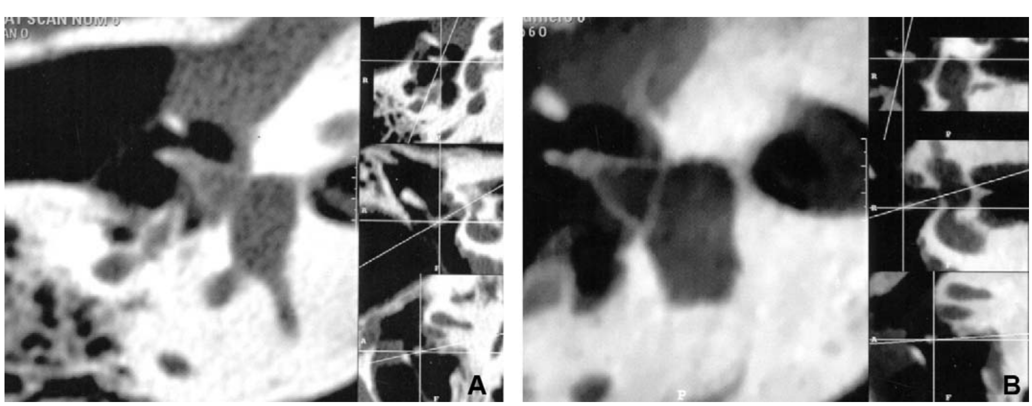

Figure 2 Temporal bone no. 6: stapes and footplate on MSCT (A) and CBCT (B). The incudostapedial joint and footplate are better defined on CBCT.

Table 3 Dosimetric comparison (CDTI in mGy) between MSCT and CBCT on unilateral acquisition.

	MSCT	CBCT	MSCT/CBCT ratio
Temporal bone 1	183	10.24	17.87
Temporal bone 2	183	6.75	27.55
Temporal bone 3	183	6.74	27.15
Temporal bone 4	183	6.94	26.37
Temporal bone 5	183	7.48	24.47
Temporal bone 6	157	9.75	16.1
Temporal bone 7	183	7.62	24.02
Temporal bone 8	172	7.62	22.57
Temporal bone 9	167	9.69	17.23
Temporal bone 10	172	6.9	24.93
Temporal bone 11	172	7.11	24.19
Temporal bone 12	172	11.2	15.36
Mean	175.83	8.17	22.3175

Discussion

Principal objective

Under the present study conditions, CBCT visualized all the middle and inner ear structures explored, including the cochlear and vestibular aqueducts, said in the literature to be a limitation in CBCT exploration [7]. The cochlear and vestibular aqueducts were systematically just as visible on CBCT as on MSCT. CBCT provides better resolution for fine bone structures, with strong density contrast [8,9].

Secondary objectives

To assess the stapes and footplate

To assess the stapes and footplate, it was decided to reconstruct not in the plane of the lateral semicircular canal but in a plane perpendicular to the footplate and in that of the two crura of the stapes. This was intended to ensure a more geometric measure of footplate thickness: the plane of the lateral semicircular canal does not cut the footplate exactly perpendicularly to its axis, and thickness is thus in principle overestimated. We expected to obtain lower plate thickness values on MSCT using this rather than the classical lateral semicircular canal axis; but in fact there was no difference in the thickness values obtained using the two axes. The thickness values obtained with an axis perpendicular to the footplate corresponded to the theoretic values determined by Veillon for normal footplates (0.4 to 0.55 mm) [5].

The double-oblique plane, moreover, enabled the crura of the stapes to be followed over the total length in a single scan slice.

The incudostapedial joint showed better definition on CBCT: the synovial joint line is more clearly distinguished on CBCT and was measurable [6].

The posterior stapediovestibular joint was less well defined than the anterior on both MSCT and CBCT, although generally considered to be wider (0.72 mm). Half of posterior joints are syndesmoses: i.e., fibrous spaces (annular ligament), rather than synovial joints with a real joint space [10]. This fibrous nature may account for the poor visualization of this joint on both CBCT and MSCT, showing no differential density with respect to surrounding bone structures.

MSCT identified the posterior less clearly than the anterior stapes crus insertion, probably due to its greater curvature. CBCT's higher spatial resolution enabled better identification.

Footplate thickness

Footplate thickness seemed closer to real values on CBCT, although this was with the theoretic histologic value as reference: a different approach would be to measure the thickness of each footplate.

Fine bone structures with high-density contrast were more clearly visualized on CBCT, with less fuzzy edges. In 2004, Gupta et al., using a Cone Beam prototype with 150 μ isometric resolution on anatomic specimens, reported better fine bone structure definition on CBCT [11]. We particularly noted the clear visualization of the bony covering of the facial canal on CBCT along the entire length from inner

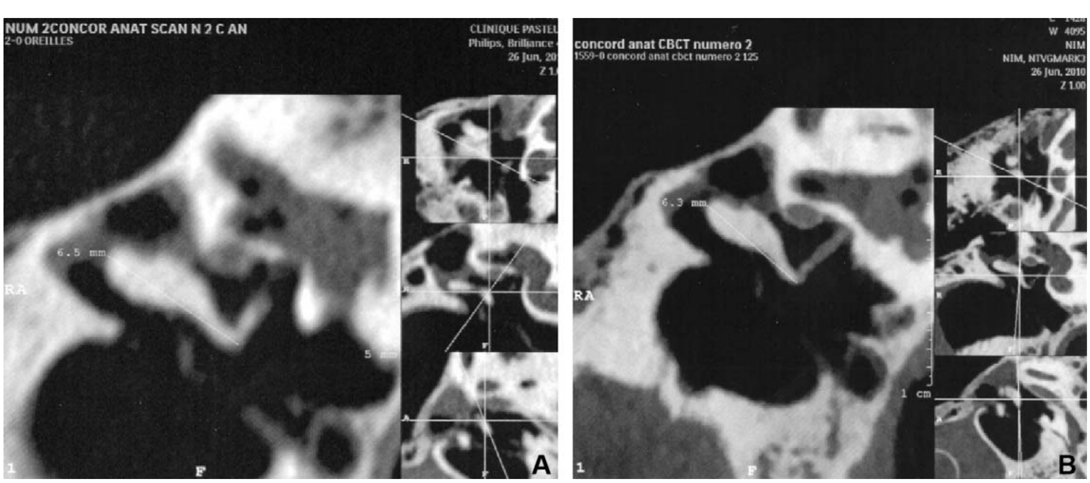

Figure 3 Temporal bone no. 2: coronal slice centered on the incus and 2nd part of the facial nerve on MSCT (A) and CBCT (B). The cortex of the facial canal is better defined on CBCT.

auditory canal to stylomastoid foramen, and especially of its second part on coronal slices (Fig. 3). Bony facial nerve canal erosion is easier to explore for on CBCT than on MSCT.

Dosimetric analysis

In line with the literature data, dosimetric analysis found a significant radiation dose reduction on CBCT. This is thanks to the conical geometry of the X-ray beam and to the pulsed rather than continuous emission. Faccioli reported 3-fold lower radiation doses on CBCT compared to MSCT, even using the MSCT scanner on a low-dose protocol [12]. According to Raffery, CBCT radiation levels are just 10% those of MSCT [13], and 6 to 10% according to Barker [14].

Under the present study conditions on anatomic specimens, all acquisitions were unilateral. Useful field of view on CBCT corresponds to a cylinder of 12* 7.5 cm, allowing complete exploration of one temporal bone specimen at a time. When bilateral exploration is required, two CBCT examinations have to be performed, increasing the radiation dose, which nevertheless remains much less than on MSCT. On the other hand, the small size of the radiated field limits radiation to the area actually being explored, protecting adjacent structures. In case of unilateral pathology, radiation is restricted to the affected side.

The principle of optimization, which is the pillar of the European Euratom Directives, mandates imaging procedures involving ''as low as reasonably achievable'' radiation exposure for a given objective.

If in vivo studies confirm the reliability of CBCT, MSCT's position as gold standard in morphologic imaging would be put in doubt.

Moreover, CBCT has other non-negligible advantages: the cost of installation and maintenance, and hence of examination, is lower (some four times less than MSCT); installation is more straightforward (on simple declaration, whereas MSCT requires authorization; also the smaller volume and lower heat emission entail less space and less onerous safety measures); and the machines can be mobile, for use in the operating room for example.

The acquisition conditions in the present experimental study were not those of clinical examination, where image quality may be greatly affected by soft tissue attenuation effects and metallic or kinetic artifacts. Indeed, our own present Cone Beam system allows examination of subjects only in seated position, which frequently leads to problems of immobilization, notably with very elderly patients or those with impaired general status. The least movement induces artifacts that reduce resolution.

The latest generation of CBCT systems allow better patient immobilization, as the posture is in dorsal decubitus. They are already on the market, and considerably reduce the incidence of movement-artifacted images.

Conclusion

Cone beam CT provides reliable morphologic assessment of the temporal bone, thanks to increased spatial resolution as compared to MSCT, and with significantly reduced radiation doses. Morphologically, it is an improvement on MSCT, to which it is fully comparable for purposes of ear pathology exploration in patients.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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