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OTOLOGY

Cone beam versus multi-detector computed tomography for detecting hearing loss

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Abstract

Objective To determine whether the diagnostic value of cone-beam computed tomography (CBCT) is equivalent or superior to that of multi-detector computed tomography (MDCT) for the radiological assessment of conductive hearing loss with intact tympanic membrane in adults. Evaluation of inter- and intraobserver variability and measurement of the radiation dosimetry associated with each technique were secondary objectives.

Study design Prospective, single-center study.

Methods Ten adults were included from April to June 2013. All patients underwent MDCT and CBCT with reconstruction of temporal bones. Two radiologists with ENT experience reviewed the results twice. Diagnostic agreement between MDCT and CBCT and inter- and intraobserver agreement was evaluated with the kappa statistic. Comparisons of dosimetry were evaluated by calculating the ratio of the CT dose index (CTDI) between MDCT and CBCT.

Results Diagnostic agreement between MDCT and CBCT was satisfactory (kappa = 0.69). Inter- and intraobserver agreement was also acceptable, and the average ratio of the CTDI of MDCT and CBCT was 4.01.

Conclusion CBCT is a reliable method that uses a low dose of radiation to investigate conductive hearing loss with intact tympanic membrane in adults. Its relevance and potential superiority to MDCT in diagnosing middle ear pathologies such as otosclerosis remain to be demonstrated, but the preliminary data are promising.

Keywords Cone beam · Diagnostic reliability · Conductive hearing loss · Temporal bone

Introduction

Multi-detector computed tomography (MDCT) is the gold-standard technique for radiological assessment of conductive hearing loss. However, this technique exposes patients to large doses of radiation. Over the past 15 years, the use of cone-beam CT (CBCT) has become increasingly common in odontology [1, 2] and craniofacial surgery [3]. CBCT is associated with a lower radiation dosage compared to MDCT [4].

In 2004 and 2006, CBCT imaging of temporal bone was first performed on human temporal bone specimens and then in patients with conductive hearing loss, respectively [5–7]. In 2007, MDCT and CBCT were compared on human temporal bone specimens [8]. CBCT was as effective as MDCT for the analysis of middle ear structures and yielded high-resolution images. However, at that time, CBCT provided a limited field of view. Current CBCT devices, which have a wider field of view, enable more comprehensive investigations of temporal bone. Since 2007, comparative studies of MDCT and CBCT have been performed on human temporal bone specimens or in vivo in post-operative follow-up of middle ear prostheses, active middle ear implants, cochlear implants, and bony anchorage hearing aids [4, 9–12]. Analysis of temporal bone structures by means of CBCT is reported to be satisfactory and associated with relatively low doses of radiation. The use of CBCT in current practice for radiological assessment of conductive hearing losses is of interest, and recent retrospective studies concluded that

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CBCT had high diagnostic reliability with respect to otosclerosis [13, 14].

Our prospective study compared the utility of CBCT and MDCT in etiological investigations of conductive hearing loss with intact tympanic membrane. The aim was to determine whether the diagnostic value of CBCT was at least equivalent to that of MDCT, with lower radiation and good reproducibility, for the radiological assessment of conductive hearing loss with intact tympanic membrane in adults. Secondary objectives were to evaluate the accuracy of MDCT and CBCT in imaging the anatomical elements of the middle and the inner ear, the inter- and intraobserver variability, the dosimetry associated with both techniques, and the discomfort experienced by patients during the exams.

Materials and methods

This study was approved by the institutional ethics committee in February 2013 (CPP Sud Est III, promotor code 2012.739). All patients signed a written consent form after receiving oral and written information and could leave the study at any time. This prospective, single-center biomedical research study was carried out jointly by the radiology and otology departments of a tertiary referral center. Patient enrollment took place from April to June 2013. Study participation was proposed by the otologic surgeon during consultation with patients with a conductive hearing loss and intact tympanic membrane. MDCT and CBCT took place on the same day: MDCT and then CBCT.

Criteria for inclusion were: adult patients (> 18 years) who required radiological assessment for conductive hearing loss with intact tympanic membrane that was confirmed by otoscopy and audiogram. Patients were not excluded if they had a history of middle ear surgery. Exclusion criteria were: pregnancy (beta-hCG blood assay < 24 h before exams in women of childbearing age), inability to express and sign consent, and weight > 160 kg (weight limit for CBCT).

The primary study endpoint was diagnostic agreement between MDCT and CBCT. Secondary endpoints were as follows.

1. Analysis of anatomical elements of the middle and the inner ear by CBCT and MDCT through the following imaging template: tympanic membrane, bony walls of the middle ear, ossicular chain, footplate, round window, facial nerve and facial canal, density of the otic capsule, and bony labyrinth elements (i.e., cochlea, semicircular canals, vestibule, and vestibular aqueduct).
2. Evaluation of inter- and intraobserver variability between two ENT-experienced radiologists (radiologist 1: 9 years of experience and radiologist 2: 2 years of experience) who interpreted both X-ray examinations while blinded. Radiologists read each exam twice, with 4–8 weeks between readings. In the event of discrepancies, a consensus reading was performed.
3. Measurement of dosimetry for MDCT and CBCT by means of the ratio of the CT dose index (CTDI) in milligrays.
4. Evaluation of discomfort felt by patients during each technique by means of a self-administered questionnaire filled out by the patient after each procedure. All of the exams were deidentified by a clinical research associate.

MDCT

The MDCT examination of the temporal bones was performed first. The device used was the MDCT Philips, Mx 8000 IDT, ten slices (Philips Healthcare, Eindhoven, The Netherlands). Two patients underwent an MDCT with a Siemens device, 64 slices (Siemens Medical Systems, Erlangen, Germany). The following acquisition parameters were used for the two devices: (1) Philips MDCT: tube voltage, 140 kV; charge at the terminals, 400 mA; collimation, 2×0.5; pitch, 0.375; rotation, 0.75 s; field of view (FOV), 200 and matrix, 1024. The scan time was 15–20 s. Reconstructions of 0.55 mm thickness every 0.27 mm were made for each temporal bone. (2) Siemens MDCT: tube voltage, 140 kV; charge at the terminals, 400 mA; collimation, 16×0.6; pitch, 0.55; rotation time, 1 s; FOV, 150 ; and matrix, 512. The scan time was 20 s. With both devices, axial and coronal reconstructions in the plane of the lateral semicircular canal were made in adjacent cross sections of 0.55 mm.

CBCT

CBCT of the temporal bones was performed with the New Tom 5G (QR srl, Verona, Italy). The patient was placed in the supine position. An amorphous silicon flat panel detector was used. Tube voltage was 110 kV, with 120 mA charge at the terminals. The FOV was 15×5 cm (diameter × height), a high-resolution filter was used, and the scan time was 40 s. The voxel size and hence the resolution was 0.075 mm. Multiplanar reconstructions in the plane of the lateral semicircular canal were made for each temporal bone with an FOV of 8×8 cm.

Statistical analysis

The study population was analyzed descriptively to define their characteristics. The diagnostic agreement between MDCT and CBCT and inter- and intraobserver variability was evaluated by the kappa statistic. The agreement is excellent if kappa is ≥ 0.81, good if it is 0.61–0.80, medium if it is 0.41–0.60, low if it is between 0.21 and 0.40, negligible if it is 0–0.2, and poor if it is < 0. Statistical analyses were

performed with Stata® version 2011 (StataCorp, College Station, TX, USA). Comparisons of dosimetry were evaluated by determining the ratio for CTDI between MDCT and CBCT for each patient.

Results

Patients

Overall, ten patients were included from April to June 2013. Nine patients had conductive hearing loss with an intact tympanic membrane and one patient had no hearing loss a posteriori (only vertigo, normal audiogram). He was, therefore, excluded from the study. The mean age was 49 years (youngest 33 years and oldest 62 years). There were six women and three men. One patient had bilateral conductive hearing loss; therefore, there were a total of ten ears with conductive hearing loss and intact tympanic membrane. Three patients had a history of middle ear surgery: two patients with bilateral, surgically treated otosclerosis and one patient with tympanoplasty.

Detected pathologies

MDCT and CBCT both identified abnormality of the ossicular chain in two patients (Fig. 1), abnormality of the footplate in four patients (Fig. 2), density abnormality of the otic capsule in two patients (Fig. 3), abnormality of the facial canal in one patient (Fig. 4), and morphological abnormality of the bony labyrinth in one patient.

Discrepancies between MDCT and CBCT were noted in six cases (Table 1). In one case, MDCT detected an abnormality (thickened and hypodense anterior crus of the stapes),

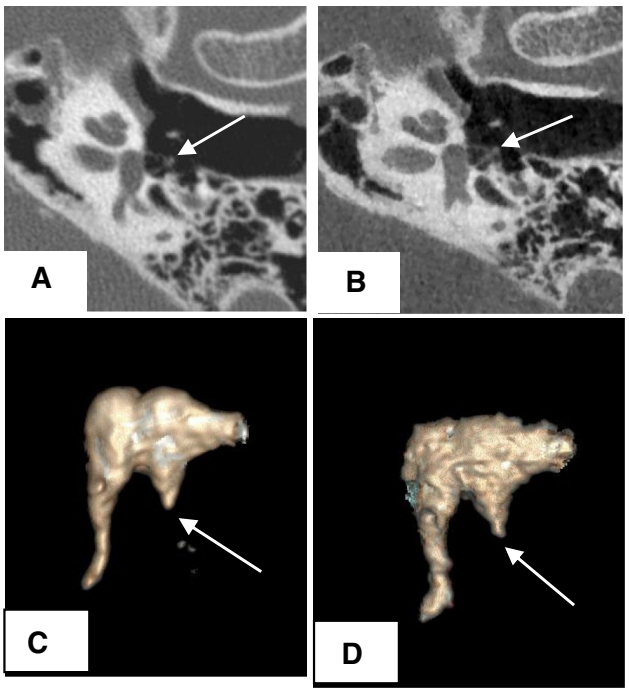

Fig. 1 Lysis of the long process of incus (arrows). **a** MDCT, **b** CBCT: left temporal bone, axial cut. **c** MDCT, **d** CBCT: 3D reconstruction

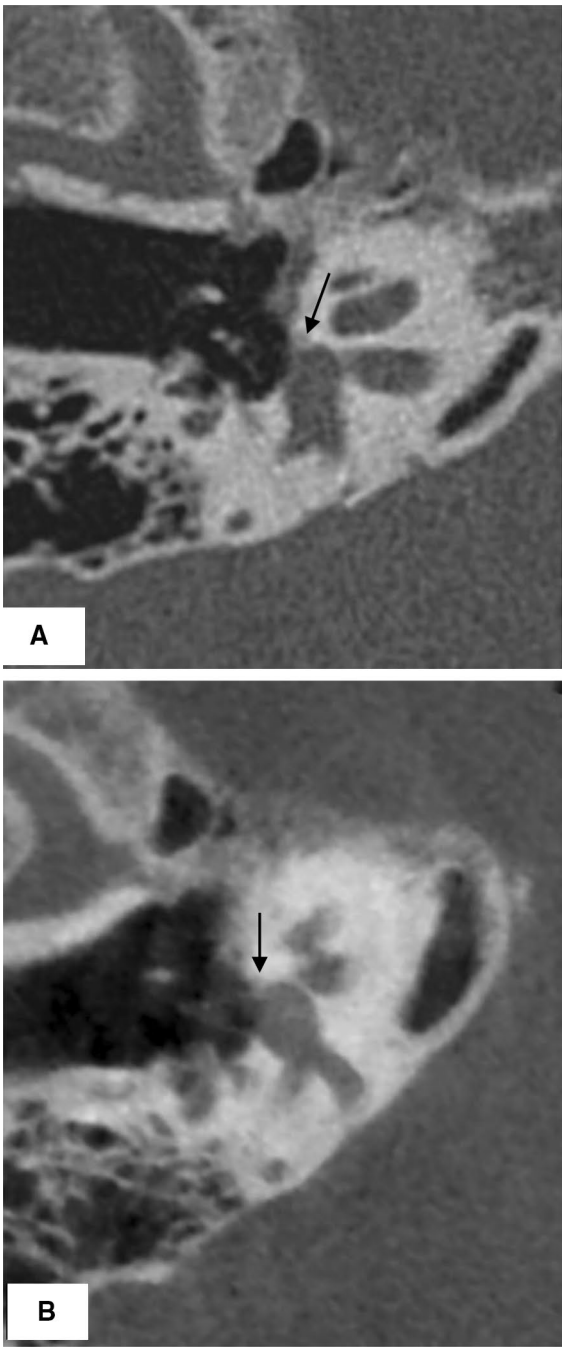

Fig. 2 Otosclerosis Ib according to Veillon staging [15]. **a** MDCT, **b** CBCT: axial cut, right temporal bone. Anterior footplate thickening and density abnormality of the fissula ante fenestram (arrows)

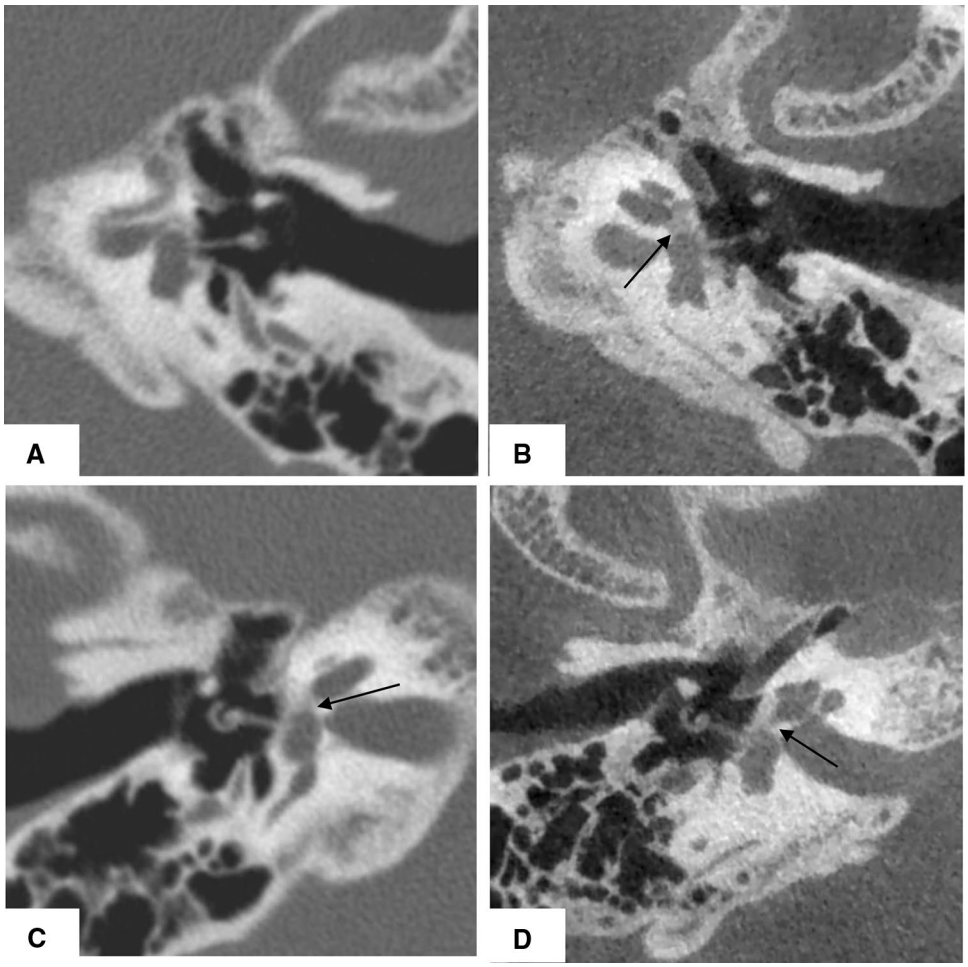

Fig. 3 Operated bilateral otosclerosis (type 3 according to Veillon staging). **a** MDCT, **b** CBCT: axial cut, left temporal bone. **c** MDCT, **d** CBCT: axial cut, right temporal bone. Thickened footplate, prosthesis in place. Pericochlear density abnormality (arrows)

while CBCT did not. In five cases, CBCT showed an abnormality (ankylosis of the stapes, thickened footplate, heterogeneous otic capsule, dehiscence of the facial canal, and fissula ante fenestram hypodensity), while MDCT did not.

Diagnostic agreement between MDCT and CBCT

The diagnostic agreement between MDCT and CBCT was satisfactory, with a kappa value of 0.69. This overall agreement was achieved by analyzing each patient for agreement of all anatomical structures listed in the imaging template: abnormality of tympanic membrane, bony walls of the middle ear, ossicular chain, footplate, round window, facial nerve and facial canal, otic capsule, and bony labyrinth elements.

An assessment of agreement between MDCT and CBCT to describe each anatomical element of the temporal bone could not be made, because the size of the study population was too small. Therefore, we performed an observational analysis between MDCT and CBCT for thickness of the footplate, facial canal, and anterior and posterior crus of the stapes. For thickness of the footplate and crus of the stapes, the CBCT found mean values that were greater than those revealed by MDCT (Table 2). For thickness of the facial canal, the mean value found with CBCT was lower than with MDCT (Table 2).

Intra- and inter-observer variability (Table 3)

The intraobserver agreement for radiologist 1 was considered satisfactory for MDCT (kappa 0.61) and CBCT (kappa 0.73). For radiologist 2, the agreement was medium for MDCT (kappa 0.48) and satisfactory for CBCT (kappa 0.78).

The kappa coefficient for inter-observer agreement for MDCT was good (kappa 0.63). For CBCT, the kappa coefficient was 0.57, indicating a moderate inter-observer agreement.

Comparison of dosimetry between MDCT and CBCT

The average ratio of CTDI between MDCT and CBCT was 4.01 (Table 4). CTDI values for MDCT were not available

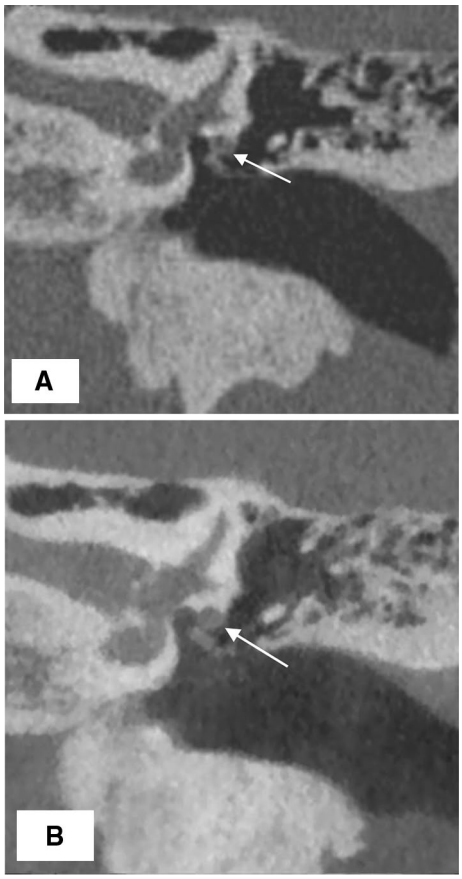

Fig. 4 Dehiscence of the facial canal (arrows). **a** MDCT, **b** CBCT—axial cut, left temporal bone

for patients 2, 4, and 7. Patient 3 was excluded from the analysis (no deafness).

Discomfort associated with MDCT and CBCT

All patients filled out a self-administered questionnaire about duration and position after each procedure. The patients indicated that all MDCT and CBCT exams were tolerable or fully tolerable. Of the nine patients, three preferred MDCT and five preferred CBCT. One patient did provide an opinion.

Discussion

In this study, we found that diagnostic agreement between MDCT and CBCT was satisfactory for radiological assessment of conductive hearing loss with intact tympanic membrane in adults (kappa 0.69). All abnormalities of the temporal bone were seen with both exams, except for in six cases. For example, an anterior crus of stapes was hypodense with MDCT and not with CBCT. This may be because CBCT is less sensitive in the analysis of low-density elements [4]. Ankylosis of the stapes was seen only on CBCT, which may be due to its superior ability in the analysis of calcified structures.

Reproducibility was satisfactory. Intraobserver agreement for CBCT was higher than for MDCT for both radiologists. For inter-observer agreement, the kappa values were good

Table 1 Discrepancies between MDCT and CBCT

	Patient no.	MDCT abnormality	CBCT abnormality
Abnormality of the ossicular chain	6	Thickened and hypodense anterior crus of stapes	0
	10	0	Ankylosis of the stapes
Abnormality of the footplate	9	0	Thickened footplate = 0.76 mm (MDCT = 0.38 mm)
Abnormality of the round window	1	0	Heterogeneous otic capsule on contact
Abnormality of the facial canal	6	0	Dehiscence at the level of stapes
Abnormality of the otic capsule	8	0	Fissula ante fenestram hypodensity

Table 2 Measures (mm) of thickness of the footplate, of the facial canal and cruses of the stapes

	MDCT			CBCT		
	Average	Median	Standard deviation	Average	Median	Standard deviation
Thickness of the footplate	0.62	0.55	0.23	0.69	0.58	0.36
Thickness of the facial canal	0.37	0.35	0.09	0.35	0.35	0.09
Thickness of anterior crus of the stapes	0.41	0.40	0.07	0.47	0.45	0.06
Thickness of posterior crus of the stapes	0.48	0.48	0.05	0.52	0.50	0.07

Table 3 Intra- and inter-observer agreement for MDCT and CBCT

	Intra observer agreement				Inter-observer agreement	
	Radiologist 1		Radiologist 2			
	MDCT	CBCT	MDCT	CBCT	MDCT	CBCT
Kappa	0.61	0.73	0.48	0.78	0.63	0.57

Kappa agreement: < 0 poor; 0–0.20: negligible; 0.21–0.40: low; 0.41–0.60: medium; 0.61–0.80: good; > 0.80: excellent

Table 4 Dosimetry (CTDI in mGy) for each patient with MDCT and CBCT

	CTDI MDCT (mGy)	CTDI CBCT (mGy)	MDCT/CBCT ratio
1	78.7	11.01	7.09
2	–	13.35	–
4	–	13.35	–
5	53.35	13.35	3.99
6	43.97	13.35	3.29
7	–	12.72	–
8	53.35	13.35	3.99
9	38.12	13.23	2.88
10	37.94	13.35	2.84
Average	50.91	13.01	4.01

(kappa 0.63) and medium (kappa 0.57) for MDCT and CBCT, respectively. CBCT is a new technology that has a learning curve. The radiologists of the study, although experienced in ENT, were unaccustomed to reading CBCT exams. This may explain the differences that we found with respect to reproducibility.

As expected, the radiation dosage associated with CBCT was lower than for MDCT (CTDI ratio for MDCT/CBCT = 4.01). Moreover, patients who expressed an opinion about CBCT found it to be fully tolerable. All in all, CBCT satisfied the requirements for radiological assessment of conductive hearing loss.

Previous retrospective studies have shown good correlations between MDCT and CBCT in describing anatomical elements of temporal bone [5–7, 10, 16–18]. In our prospective study, we demonstrated that the CBCT New Tom 5G allows for complete and high-resolution analysis of temporal bone when investigating conductive hearing loss.

We identified several otosclerosis injuries with both exams. CBCT appears be a reliable means of analyzing heterogeneity of the otic capsule. Liktor et al. [14] concluded that there was good reliability for CBCT with respect to preoperative diagnosis of otosclerosis. Redfors et al. [13] stated that CBCT is a satisfactory technique for determining the piston position. Our results were in concordance with these previous findings. Dahmani-Causse et al. [19] found that measurements of the thickness of the footplate with CBCT were closer to anatomical reality compared to MDCT. This comparison was performed by means of histologically measured values for footplate thickness [20].

In our study, the thickness of the footplate was greater when measured by CBCT. This may be due to the fact that one of the patients who had surgery for otosclerosis underwent plugging on the footplate. While MDCT could distinguish between the plug and the footplate when measuring footplate thickness, this was not possible with CBCT. This partly explains the average difference and overvaluation with CBCT.

For thickness of the facial canal, CBCT found the lowest thickness (0.35 mm versus 0.37 with CBCT and MDCT, respectively). CBCT should lead to a better assessment of bony structures because of its better resolution of the bone framework. Eidenberg et al. [21], in their study of dehiscences of the semicircular superior canal, found that CBCT was closer to anatomical reality than MDCT and overestimated fewer dimensions of bony defects.

In recorded discrepancies between MDCT and CBCT, in one case, the otic capsule was considered to be in heterogeneous contact with the round window with CBCT but normal with MDCT. A hypodensity of the fissula ante fenestram was seen only with CBCT. It is possible that CBCT is more sensitive than MDCT for exploration of the otic capsule, which is a compact bony structure, but this assumption needs to be evaluated in a larger population.

Our study had several limitations that should be considered. First, the size of the population was small. The number of included ears allowed us to calculate the global agreement between MDCT and CBCT, but statistical tests for each anatomical element of the temporal bone could not be carried out. In addition, this study did not allow us compare radiological data with respect to surgical or anatomical considerations. Second, concerning radiation, we only measured dosimetry in terms of the CTDI and not as effective dosages of radiation. Dierckx et al. [22] investigated the effective dose of radiation associated with the CBCT New Tom 5G with acquisition parameters identical to ours. They found that the effective dose of radiation with CBCT was 0.4 mSv, while it was 2.33 with MDCT (i.e., six times lower with CBCT). Our dosimetric study yielded a CTDI ratio of 4.01 between MDCT and CBCT, which is in accordance with previous findings [4, 17–19].

Our study demonstrates the need for additional prospective studies with a larger population to validate the reliability of CBCT for radiological assessment of conductive hearing loss in adults. This would allow researchers to evaluate the accuracy of CBCT in analyzing the footplate and could even redefine otosclerosis staging if CBCT yields results that are closer to the anatomical data than MDCT. Comparing imagery data with preoperative data or human cadaveric temporal bones would be an important next step. CBCT may also be superior at imaging semicircular canal dehiscence [22] or the facial canal; it should be closer to anatomical reality than MDCT.

In summary, CBCT is a reliable imaging technique associated with a relatively low amount of radiation that may be used to investigate conductive hearing loss with intact tympanic membrane in adults. Its relevance and potential superiority compared to MDCT in middle ear pathologies such as otosclerosis need to be demonstrated, but preliminary data are promising.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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