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UPDATE

Cone-beam imaging: Applications in ENT

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3D imaging;
Head

Summary Cone-beam imaging is an X-ray based volume acquisition method providing 3D images of the head. The reconstructed volume is ''isotropic''; spatial resolution varies according to material, equaling or exceeding that of CT but with a much lower radiation intensity. The drawbacks comprise a reduced signal-to-noise ratio and poor density resolution precluding soft-tissue exploration, notably of tumoral processes. This technique is very effective for the study of inflammatory and infectious processes of the head. In dental exploration, its intrinsic qualities enable screening for sinusitis of dental origin with a precision unobtainable on CT. Cone-beam imaging will, in the near future, become the reference examination in sinus assessment. Finally, this technique, at least using the most powerful apparatuses, seems very promising in ear pathology exploration. First applications in chronic otitis, dysplasia, deformity and trauma have been encouraging. Its low sensitivity to metallic artifacts makes it the technique of choice in the follow-up of cochlear implants.

Introduction

Cone beam imaging or Cone Beam Computed Tomography (CBCT) is a volume acquisition method introduced just before the year 2000. It was first intended for dental study of relative dimensions and pre-implantation assessment, providing orthodontists and implantologists with useful images; its acceptance, however, was limited as quality was much poorer than with CT. Ten years on, significant improvements and the emergence of certain intrinsic advantages have considerably changed the outlook, with respect not only to dentomaxillary imaging but also to sinus and petrosal bone exploration.

General considerations

Technology

A combined X-ray tube and plane detector turns around the patient's head during pulsed or continuous X-ray emission. The series of images acquired by the plane detector during rotation is processed by the computer to obtain a cylindrical numeric volume, which is used to reconstruct three series of parallel slices in three orthogonal planes. Within the numeric cylinder, each volume unit (voxel) is cubic in shape, and the volume is said to be isotropic. This ensures identical spatial resolution whatever the slice orientation within

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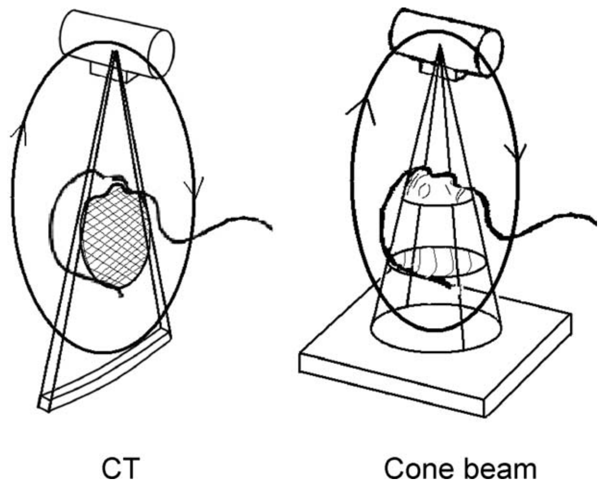

Figure 1 Comparative representation of acquisition in CT (slice) and CBCT (volume).

the volume. CT, on the other hand, reconstructs volume by superimposition of slices (Fig. 1), and the constituent voxels are rarely cubic in shape. The volume is said to be ''anisotropic''; spatial resolution varies according to slice orientation.

Cone beam; X-ray; 3D imaging; head

Information processing is similar in CBCT and CT: multiplanar (axial, coronal, sagittal) slice reconstruction (MPR) plus oblique reconstruction if needed.

Acquisition design

Acquisition design, on the other hand, differs. In most CBCT apparatuses, the patient stands or sits in a vertical posture. One manufacturer (Newtom) has developed a supine-posture device as in CT. This vertical positioning requires secure immobilization of the patient's head, as acquisition time (7—30 sec) is considerably longer than in multislice CT.

Advantages

Radiation [1—5]

Cone-beam imaging's key feature is its radiation intensity, which is notably lower than in CT, whether for sinus or ear exploration. For example, the Computed Tomographic Dose Index (CTDI) of a CT scan of the middle ear is around 170 mGy, compared to 15—30 mGy for cone-beam imaging. This makes CBCT the technique of choice in pediatric ENT or in case of iterative examination.

Voxel isotropy and spatial resolution

Image quality in terms of spatial resolution is determined by voxel size. If the voxel edge is short, spatial resolution is as good if not better than in CT, providing 3D images of great precision, especially as regards bone structure, and moreover in all spatial directions thanks to the isotropicity of the voxels (Figs. 2 and 3).

Metallic artifacts

Cone-beam imaging produces fewer artifacts around dense metallic structures than does CT. This advantage is particularly noticeable around surgical and prosthetic material, dental crowns, intra-sinus metallic foreign bodies and cochlear implants.

Drawbacks

Density resolution

Low radiation intensity comes at the cost of a much narrower density scale than on CT, and thus less fine discrimination of

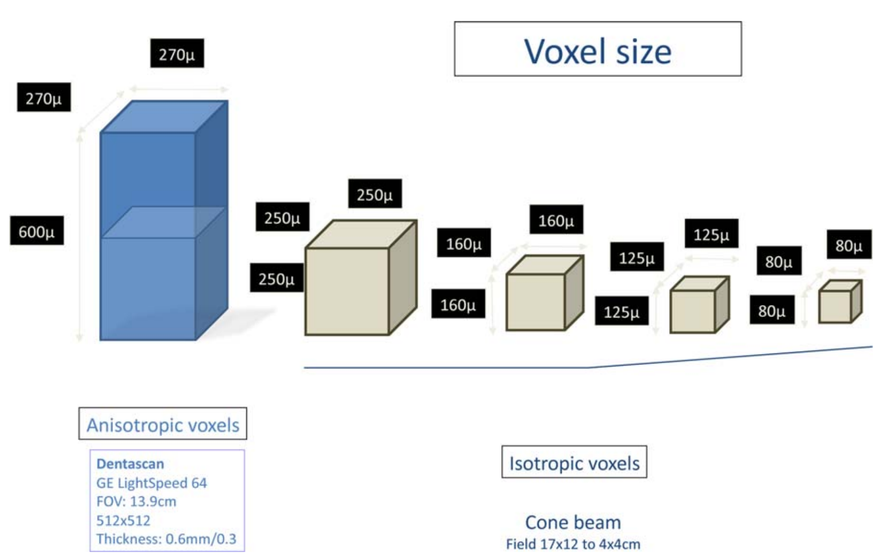

Figure 2 Comparison of voxel form and size. A: Anisotropic voxel, DentaScan protocol. B: Voxel sizes available according to exploration field size on the MORITA®Accuitomo 170 cone-beam apparatus.

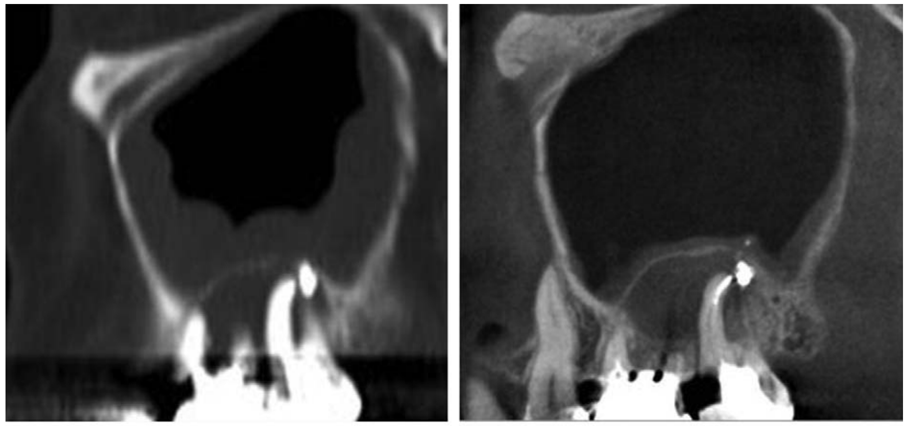

Figure 3 Comparison between CT scan (a) and cone beam image (125 μ voxels) (b) of a radiculodental cyst excess dental filling paste on tooth 27 and sinus mucosal thickening reaction. Two week interval between 2 examinations. Assessment of bone structure, of precision of cyst wall and root study and of metallic artifacts.

soft-tissue density. The Hounsfield scale does not exist, and density is adjusted by simple modulation of blackening and contrast. This precludes both study of soft-tissue extension of pathological processes (tumor, infection or facial blood effusion) and contrast medium injection. The discovery of soft-tissue invasion by any kind of process therefore means that con-beam imaging has to give way to CT and/or MRI.

Noise

The signal-to-noise ratio is an essential factor in image quality. The signal corresponds to the voxels supplying information and noise to parasite voxels that degrade image quality. Here again, low radiation intensity means increased noise levels, which may not always be perceptible but cause problems for high-resolution and high-contrast studies, notably of the middle ear.

Implications for cone-beam examinations

Spatial resolution and exploration field size

The characteristics of the slices obtained depend on three mutually antagonistic factors: voxel size, explored volume, and IT capacity and calculation speed. All cone-beam acquisitions are based on a compromise struck between these three. Thus, for a given calculation time, the wider the field the poorer the spatial resolution. Global sinus study uses a large field, but exploration for a dental site implicated in sinusitis will need a smaller field with better spatial resolution. Certain apparatuses include a **retro-reconstruction function**: the computer reconstructs one selected part of the volume with enhanced spatial resolution, enabling, for example, precise dental apex study after large-field global sinus acquisition (Fig. 4).

Noise

Noise increases as voxel size and slice thickness decrease. This is a limitation for petrosal bone exploration, especially in the middle and inner ear where high spatial resolution is sought in thin slices with minimal noise. The middle ear is the best place to judge the quality of the various machines available on the market (see below).

Applications in ENT imaging

Sinuses and nasal fossae

The quality of cone-beam images and the ease of implementation and reading with MPR visualization on CD-ROM provided for each examination make them particularly practical and user-friendly.

Inflammatory pathology

Air-mucosa-bone contrast is excellent, allowing very interesting study of air cavity anatomy and ventilation. Effusion, mucosal thickening and ostial obstruction are perfectly visible, with precision equal to or greater than that of CT. Any inflammatory or infectious sinus pathology is accessible to cone-beam examination, with complete topographic exploration [6]. However, as with CT without contrast injection, it is not possible to distinguish between simple mucosal thickening, mucosal cyst, polyp and retention. Only detection of a horizontal level indicates the liquid nature of filling.

Fungal sinusitis

Relative lack of metallic artifacts and good spatial resolution enable detection of fine calcifications associated with aspergillus graft around intra-sinus metallic foreign bodies, usually of dental origin. In the absence of such calcification, the aspect of the superior border of the intra-sinus opacity, suggestive of aspergilloma, may also guide diagnosis (Fig. 5).

Study of tooth/sinus relations

Cone-beam imaging shows its advantages over CT in the study of tooth/sinus relations. High-resolution exploration ($\leq 120\,\mu$ voxels) can get inside the tooth, revealing acces-

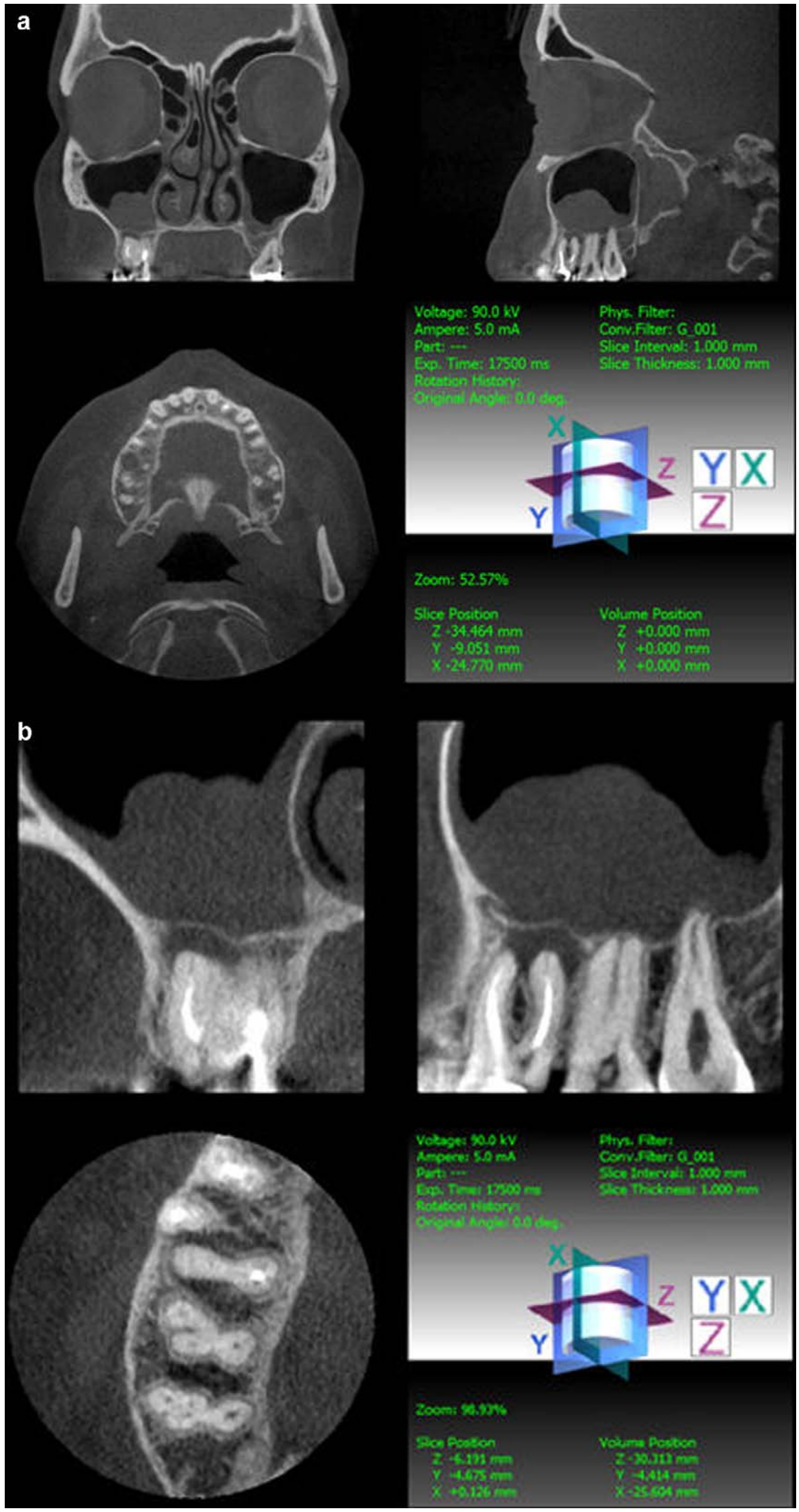

Figure 4 Large-field acquisition (14x10 cm), 250 μ voxels, on facial bone. b: Retro-reconstruction centered on the apices of 16, with 125 μ voxels: radiculodental cyst on incomplete filling of distal vestibular canal of tooth 16, microperforation of sinus floor and facing mucosal thickening.

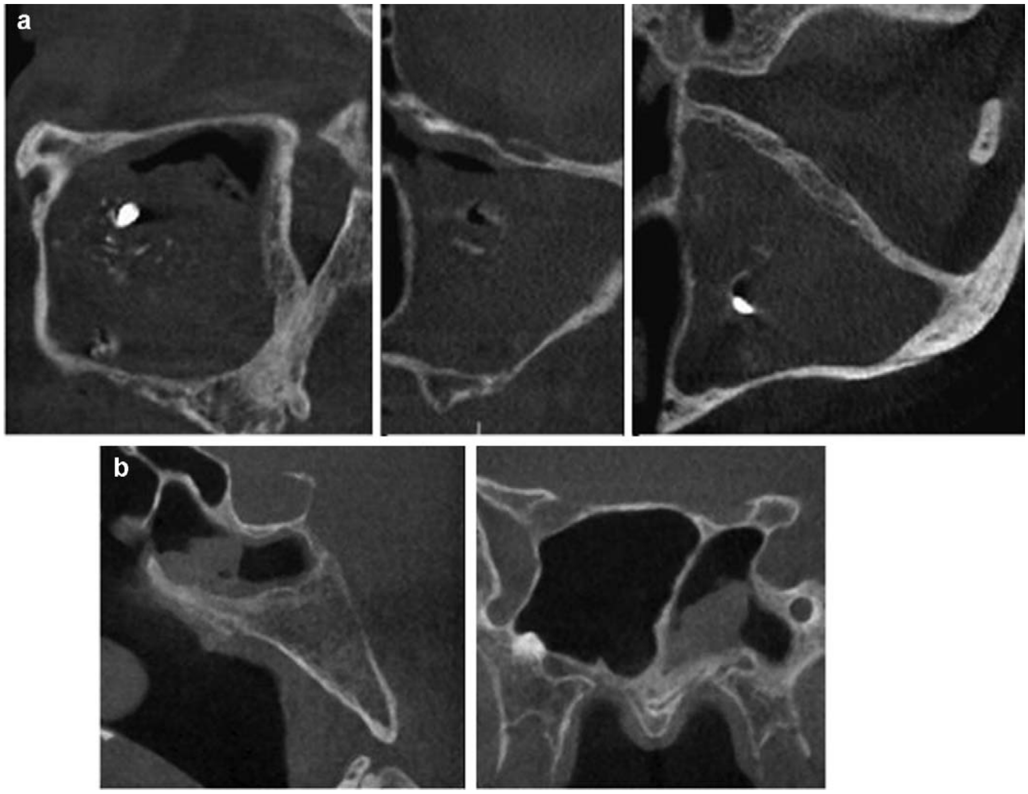

Figure 5 a: Fungal sinusitis with aspergillus graft manifesting as calcified filaments around a fragment of dental filling paste in the left maxillary sinus. b: Left sphenoid sinus opacity with fungus ball aspect, despite absence of calcification. Diagnosis confirmed peroperatively. Coronal and sagittal slices.

sory or supernumerary canals, incomplete or absent filling, root fissure, instrumental perforation and endoperiodontal lesions. Access is given to microperforations of the sinus floor facing apical dental sites [7], and to buccosinus communications (Figs. 4, 6—9). Such precision is not presently available on conventional CT under normal sinus examination conditions (Fig. 3).

Bone remodeling and mucosal calcification

Study of fine bone remodeling requires good spatial resolution. This is the case for assessment of bone extension of infectious processes of dental or sinus origin, fine perforation or blurring of sinus floors and cortices opposite dental sites, intraosseous fistular trajectories, and thinning or blurring of walls. Mucosal calcification, along the wall by osseous metaplasia of Schneider's membrane during subacute or chronic inflammatory processes, can also be detected (Figs. 10, 11 and 12).

Postoperative assessment

Cone-beam imaging, with its low radiation intensity, is well adapted for postoperative follow-up. It is, of course, to be restricted to benign sinus lesion surgery, with CT and MRI still used for postoperative follow-up of malignancies.

Trauma

Exploration for traumatic lesions of the head can be performed by CBCT under certain conditions:

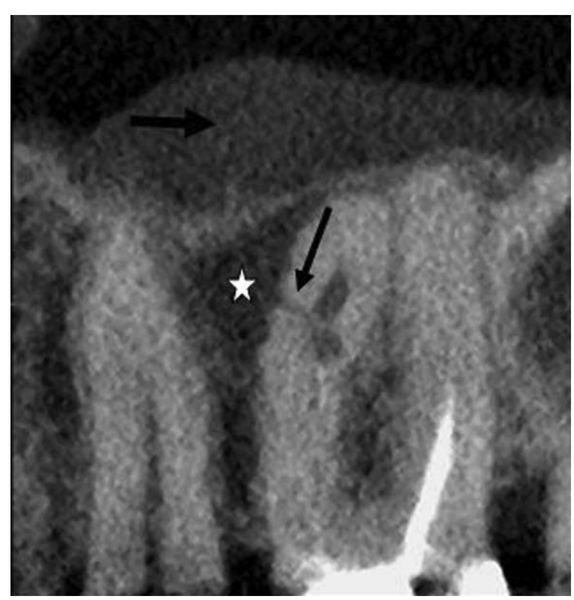

Figure 6 Intra-canal site communicating with juxtaradicular space (star) via an accessory canal (black arrow). Reactive mucosal thickening in facing sinus (black arrow).

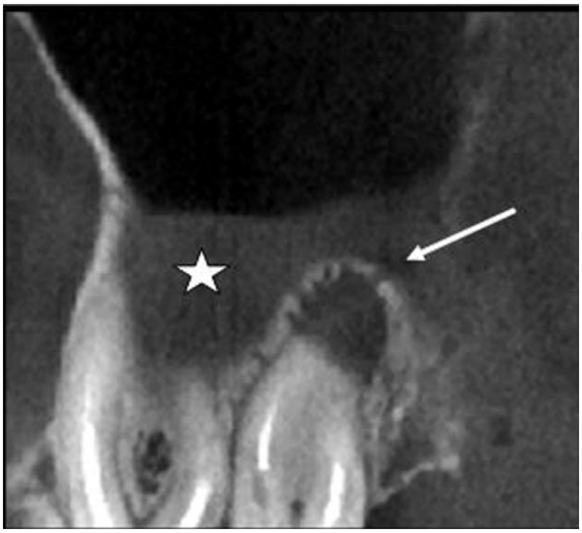

Figure 7 Radiculodental cyst with microperforations of the wall and intrasinus effusion opposite (star).

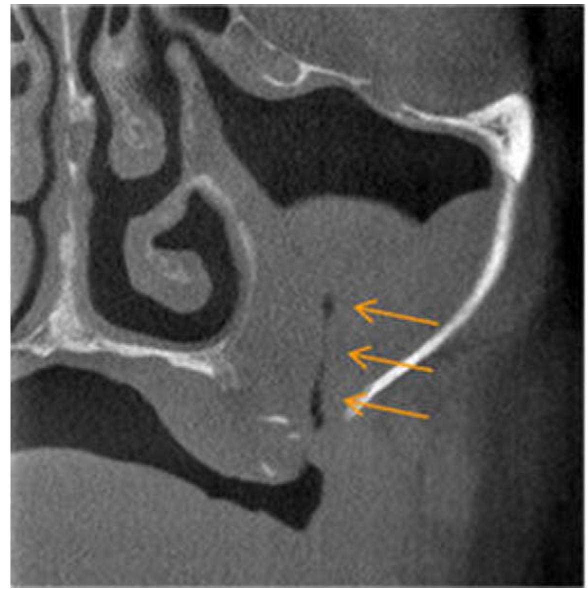

Figure 9 Bucco-sinus communication after tooth extraction. The gaseous fistula is clearly visible (arrows).

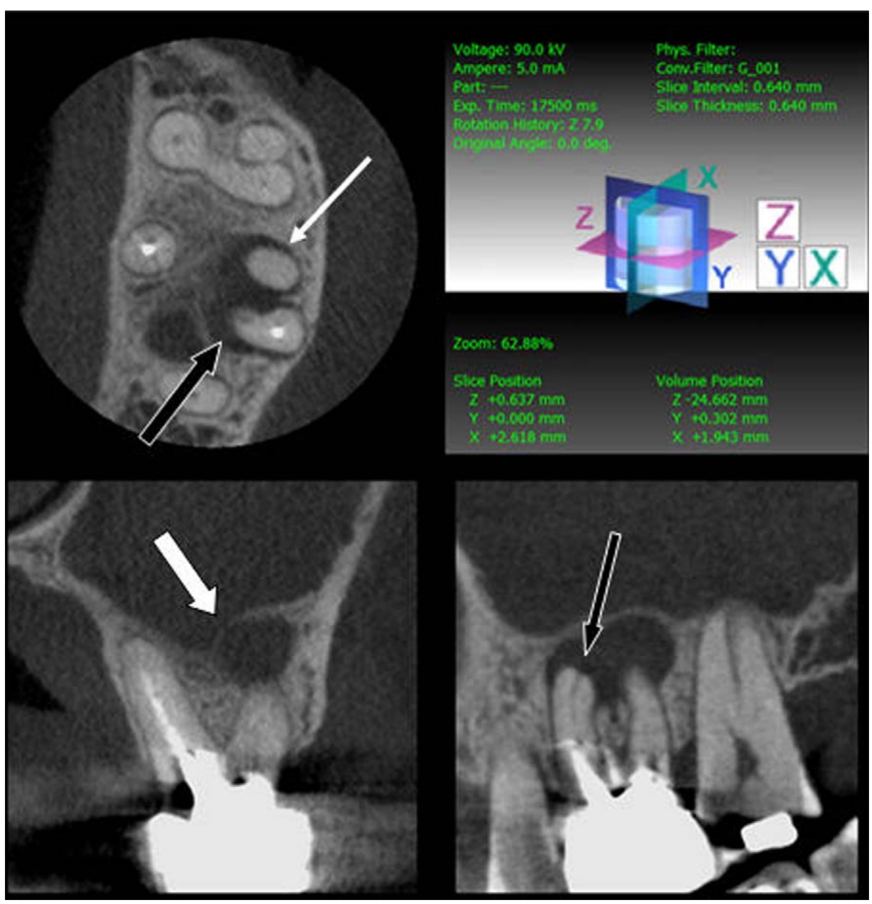

Figure 8 Apical dental site communicating (wide black arrow) with the right maxillary sinus, which is filled. On tooth 26, no distal vestibular canal filling (thin white arrow) and a 4th previously undetected median palatine canal (black arrow).

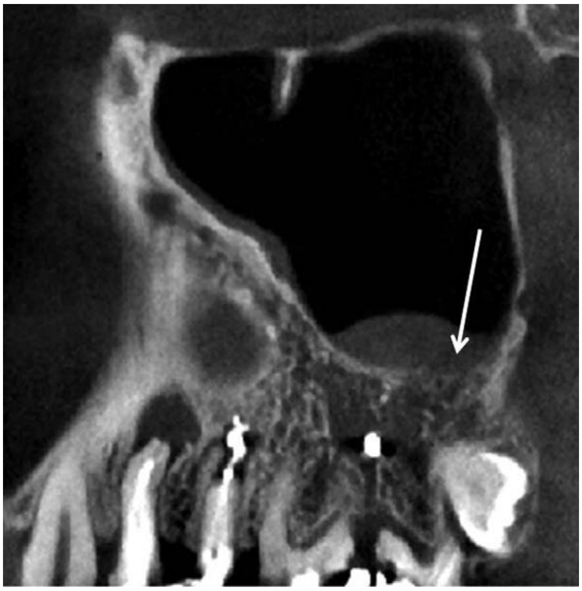

Figure 10 Site of maxillary osteitis of dental origin. Extension to sinus floor, which appears blurred posteriorly (arrow), with facing sinus mucosal reaction.
Extract of: Hodez C, Bravetti P. Imagerie dento-maxillo-faciale par faisceau conique: ''cone beam''. Montpellier: Ed. Sauramps Médical; 2010.

- sufficiently large field to cover the entire trauma area;
- sufficient spatial resolution, whatever the field size, to detect fine bone lesions.

It should be borne in mind that the technique's poor density resolution may hinder detection of cranioencephalic, orbital, sinus or facial soft-tissue hematic effusion; CT remains the reference examination in severe maxillofacial trauma.

Cone-beam imaging is performed on an ambulatory basis and often late with respect to the trauma when limited in extent and severity. The good spatial resolution and volume rendering enable excellent study of small maxillomandibular fractures or fractures involving the nasal bones, sinus or orbital walls, or mandibular condyles. Gas infiltration in orbital or perisinus cellular spaces can be very easily detected [8] (Figs. 13 and 14).

Tumoral pathology

If a tumor invading the soft tissue is discovered, CT and/or MRI are mandatory. Intraosseous tumor, on the other hand, may be explored on CBCT as long as no contrast enhancement is needed, enabling excellent topographic study of bone extension, any intratumoral calcification or perilesional thin osseous wall.

Salivary glands

Cone-beam imaging is not going to revive sialography, indications for which are giving way to ultrasound and sialo-MRI. Very fine images and 3D reconstructions can nevertheless be obtained, but the information provided is not much better than with sialography. We have been able to detect some Wharton's canal calculi missed on US scan and very difficult to discern on sialography. The medial part of the parotid is also easier to distinguish than on sialography (Fig. 15a). More interesting perhaps is exploration without opacification of the floor of the mouth and the submaxillary space in case of colic salivary symptomatology, where the contribution of US is slight if any. The smallest radio-opaque calculus appears immediately (Fig. 15 b and c).

Exploration of pars petrosa and cranial base

CBCT's advantages in terms of spatial resolution and radiation levels could make it the most efficient means of exploring the fine structures of the ear and cranial base. The possibility of using fields of varying size on the same apparatus optimizes exploration of regions of interest. Slices thicknesses around 80—120 μ with isotropic voxels enabling multiplanar reconstruction provide a key advantage in temporal bone exploration. The low radiation level, however, means that noise is about 50% greater than on CT [9], and

Figure 11 Juxtaparietal Schneider's membrane calcification by bone metaplasia.

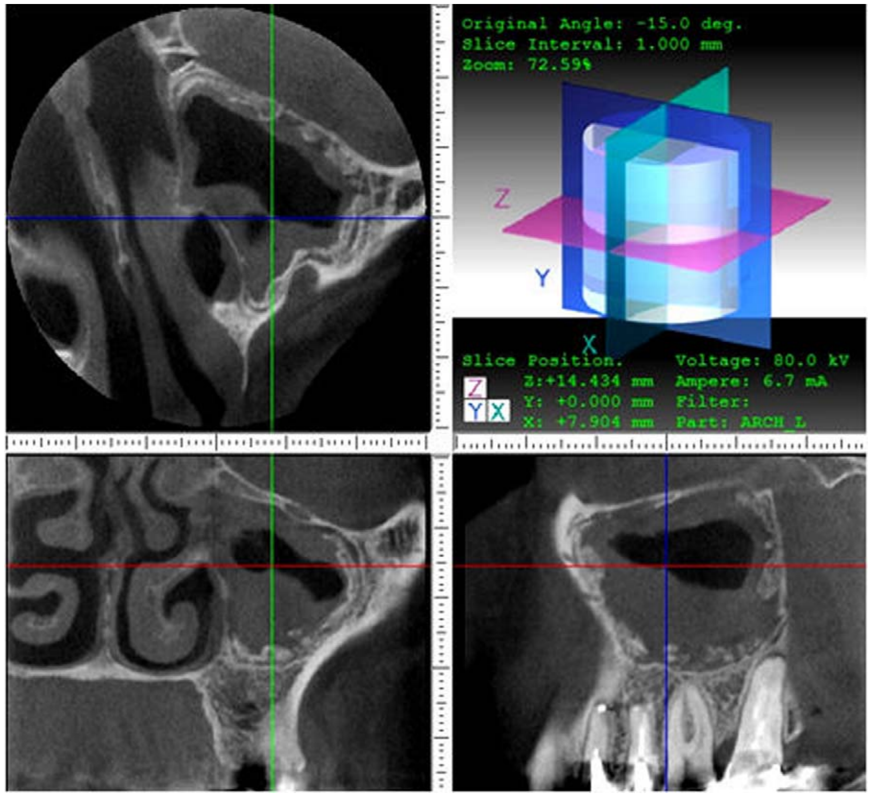

Figure 12 Chronic sinusitis. Apposition of juxtaparietal calcifications of mucosal origin, progressively inducing sinus bone wall thickening.

density resolution is poorer (see above). These elements may restrict indications. Cone-beam imaging explores bone structures, but does not give access to inner auditory canal content or soft-tissue structures around or within the pars petrosa.

Temporal bone aspect on cone-beam image

The lower signal-to-noise ratio gives a slightly different aspect than on reference (CT) imaging. The esthetic and diagnostic qualities of an image, however, are not the same thing [10]. The cone-beam image gives access to plentiful and sufficient diagnostic information if the indications for CBCT are correct. It should always be borne in mind that minimal radiation is an important factor in indications for imaging assessment by X-ray, and that radiation-free or radiation-light techniques of equal diagnostic quality should always be preferred [11].

First results

Many studies performed on anatomic specimens since 2004 [12] demonstrated the quality of spatial resolution in the ear, and particularly in the ossicular chain [13,14].

Inner ear study of the labyrinth seems to be of less good quality than with CT, due as usual to the impaired signal-to-

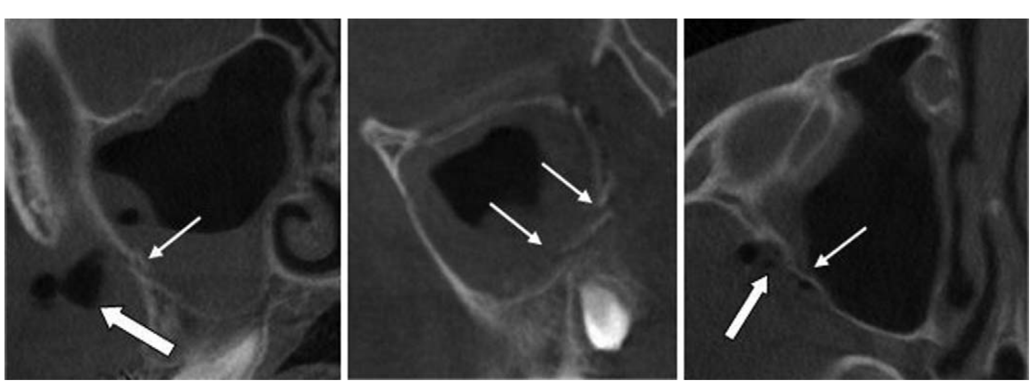

Figure 13 Direct trauma. Fracture of the posterior wall of the right maxillary sinus (thin arrows) and juxtaparietal soft tissue emphysema (thick arrows). Slight blood effusion in sinus.

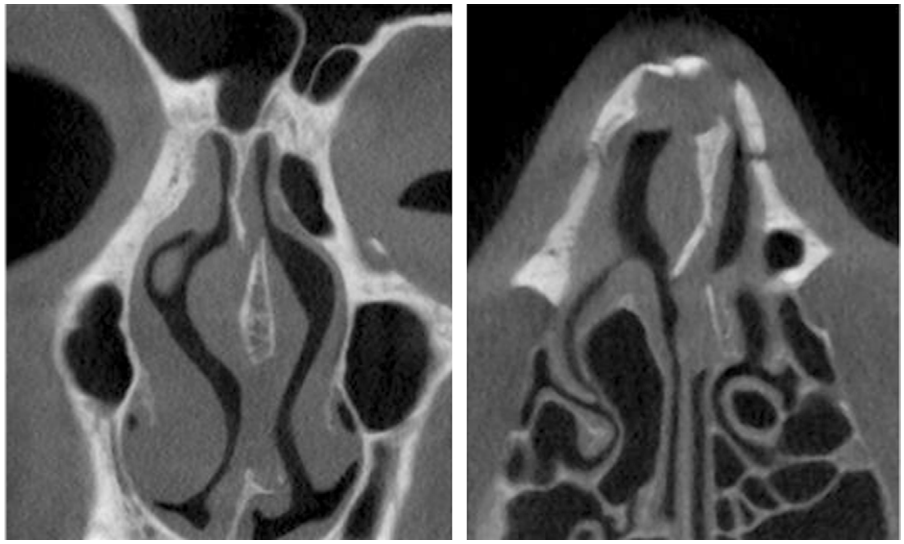

Figure 14 Nasal bone fracture and displacement fracture of nasal septum.

noise ratio. Even so, the image enables acceptable study of the osseous labyrinthine structures [15,16].

Study of middle ear air content also shows a noisy image, hindering interpretation of small mucosal or inflammatory opacities, but still allowing satisfactory study of bone or ossicular involvement around middle ear or mastoid opacities. Discovery of a fistula in the thin osseous labyrinthine wall or a Fallopian canal lesion is not a problem.

The few in vivo studies so far performed confirm the results found on anatomic specimens [17].

Image acquisition protocols

These protocols have been described elsewhere [18], and will not be detailed here; moreover, they vary from one apparatus to another, but must always meet certain diagnostic imperatives.

The cranial base

For the study of the cranial base, the field should cover the entire base, at the price of some loss of spatial resolution.

The pars petrosa

For the study of the pars petrosa, on the other hand, spatial resolution should be optimized, using small fields, which entails side-wise acquisition. This increases overall radiation, which nevertheless remains much lower than in CT (see above). It should be borne in mind that noise increases with diminishing voxel size and that the various machines on the market have very different performances in this regard.

Certain machines allow high-resolution **retro-reconstruction** of small fields selected from a large-field acquisition (see above). Unfortunately, experience shows that the quality of the reconstructed images is slightly lower than that obtained with two separate small-field acquisitions (Fig. 16). We do, however, use retroreconstruction to explore the temporomandibular joints, for which the spatial resolution is quite sufficient [19].

Image rendering

The presentation of the results is equivalent to CT; all recommendations regarding CT reading apply to CBCT.

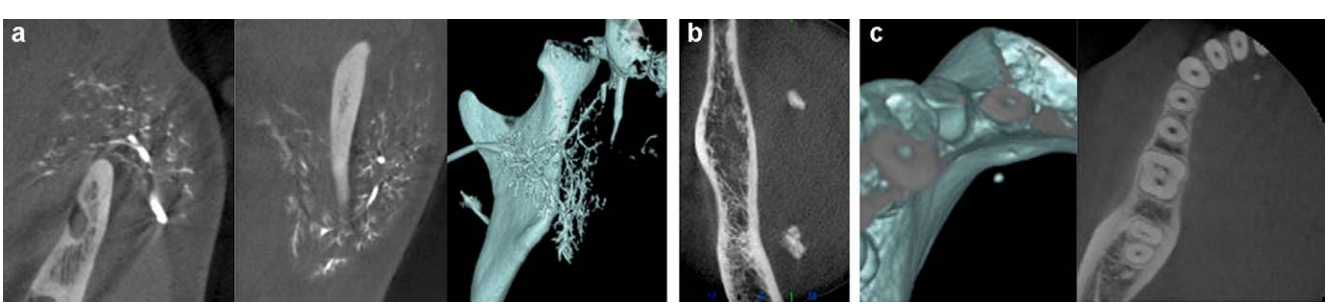

Figure 15 a: normal parotid sialography. Axial and sagittal slices and reconstruction with volume rendering. b: exploration without injection. Two calculi in Wharton's canal; c: exploration without injection. Small calculus enclosed in distal Wharton's canal.

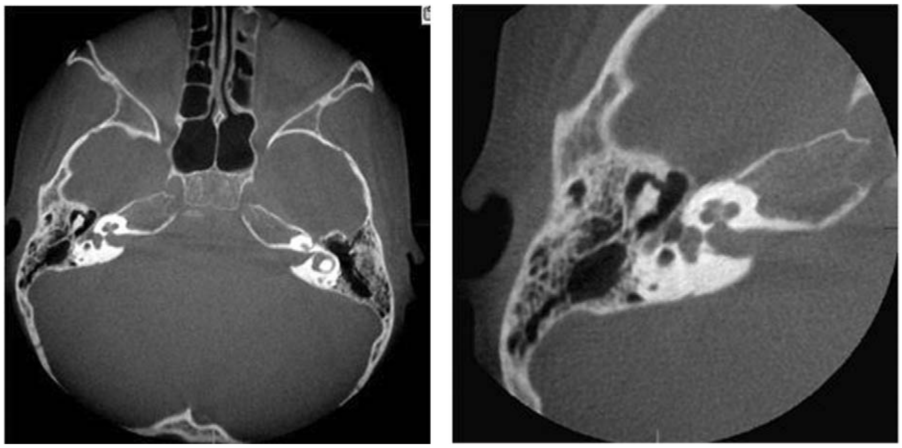

Figure 16 a: bilateral large-field acquisition (250 μ); b: unilateral retro-reconstruction (125 μ). Taken from ''Imagerie dento-maxillo-faciale par faisceau conique : ''cone beam'', C. Hodez, P. Bravetti, Sauramps Médical, Montpellier, 2010.
Extract of: Hodez C, Bravetti P. Imagerie dento-maxillo-faciale par faisceau conique: ''cone beam''. Montpellier: Ed. Sauramps Médical; 2010.

Figure 17 Oblique axial reconstruction along stapes axis. Very good visibility of stapes anatomy, respecting the different diameters of the anterior and posterior branches (not always clear on CT). Note good visibility of the turns of the spiral canal of the cochlea, although the spiral lamina is not visible on this image. The mineralization of the prestapedial area and the footplate are easily accessible; a: Morita (photo, C. Hodez and C. Griffaton); b: CareStream (machine under development; MPR reconstruction (Osirix software, University of Geneva); c: Newtom VGi V5 (NB: reconstruction on Osirix software does not use the cone-beam manufacturers' specific filters).

Results for the temporal bone

Pars petrosa study in a well-pneumatized middle ear is as least as good as with high-resolution CT with 500—350 μ slices. The 125—80 μ reconstructed slice thickness on CBCT provides much better images of the ossicular chain, notably as concerns the stapes (Fig. 17).

CBCT inner ear imaging is sufficient to diagnose most malformations and dysplasia, traumatic lesions and thin osseous labyrinthine wall erosion or dehiscence (Figs. 18 and 19).

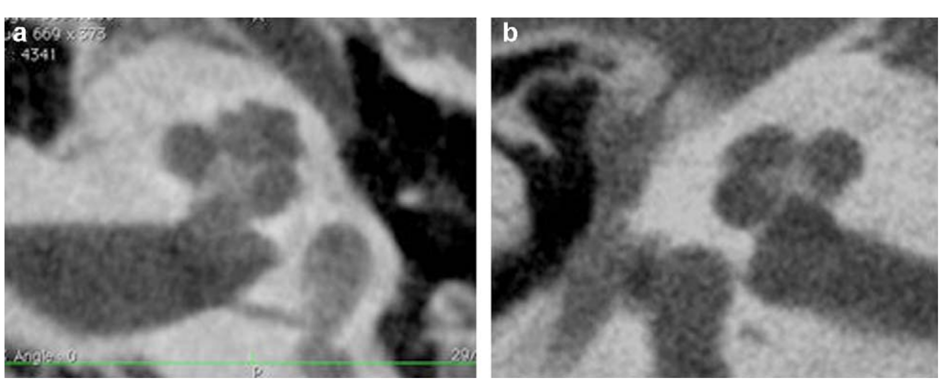

Figure 18 Axial reconstruction, cochlea and modiolus (normal aspect): a: image on CareStream apparatus; b: 80 micron slice, 90KV, 8 mA. Taken from ''Imagerie dento-maxillo-faciale par faisceau conique : ''cone beam'', C. Hodez, P. Bravetti, Sauramps Médical, Montpellier, 2010.

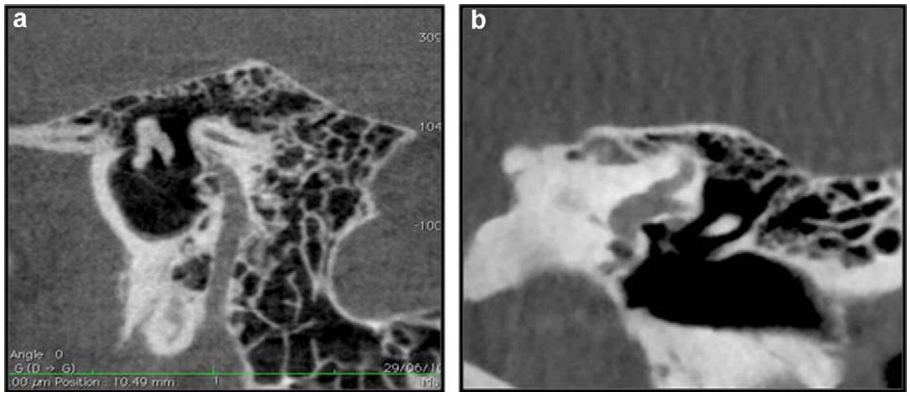

Figure 19 Fallopian canal; a: Sagittal reconstruction, 3rd part of normal facial bone, using OSIRIX software on CBCT DICOM data. 90 micron slice on CareStream apparatus (under development for ear application), 90 KV, 10 mA b: Coronal reconstruction on 2nd part of facial bone; Newtom VGi V5 apparatus, 90 KV, 10 mA.

Malformation and dysplasia

CBCT is probably the most effective imaging technique for anatomic study of the ossicular chain, thanks to its excellent spatial resolution. Ossicular chain malformation or fixation, bone dysplasia and otospongiosis sites are clearly visible (Fig. 20).

Chronic otitis

In chronic otitis with dense pars petrosa and middle ear opacity, cholesteatoma and associated complications can be diagnosed on CBCT. As in CT, diagnosis is not based on specific lesion density but on the impact on neighboring bone structures (middle ear walls, ossicular chain, thin osseous labyrinthine wall, and osseous Fallopian canal). All these structures are clearly visible on CBCT, even in case of middle ear opacity (Fig. 21).

Trauma

Experience is presently more limited in France, but CBCT is probably effective for traumatic pars petrosa bone lesions, although it must be borne in mind that associated soft-tissue and cerebral lesions will not be visualized.

On the other hand, CBCT is very probably more effective than CT for microlesions of the ossicular chain, especially in the footplate and stapedial branches.

Tumor

For obvious or suspected tumoral lesions, CBCT is not indicated: CT and MRI are required.

Vessels

Likewise, MRI and angioscan remain mandatory in vascular pathology.

Postoperatively

Follow-up of ossiculoplasty and residual air-bone gap are indications for CBCT. Postoperative follow-up of cholesteatoma is increasingly dependent on MRI, but residual surgical cavity opacity can be effectively explored by CBCT.

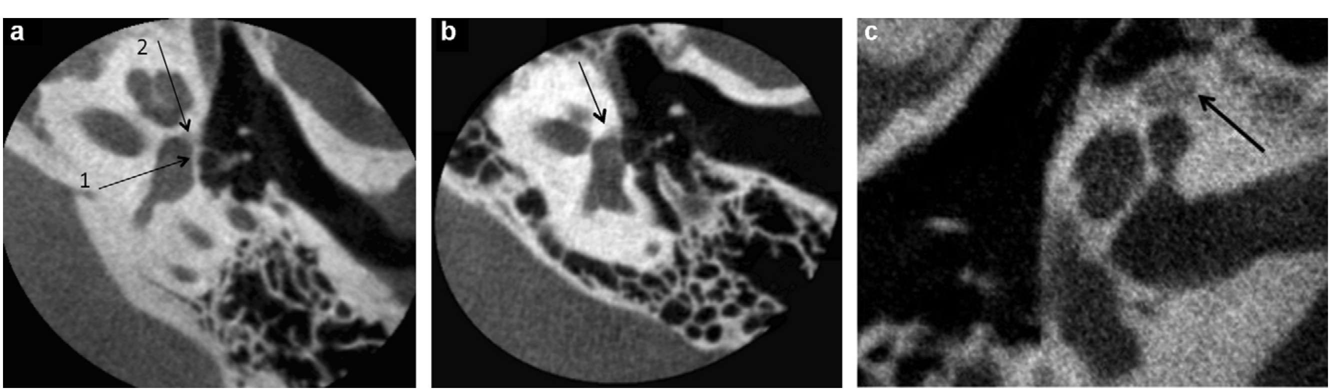

Figure 20 Otospongiosis; a: Stapedovestibular otospongiosis site. Taken from ''Imagerie dento-maxillo-faciale par faisceau conique : ''cone beam'', C. Hodez, P. Bravetti, Sauramps Médical, Montpellier, 2010; b: prestapedial otospongiosis site (photo, C. Hodez and C. Griffaton); c: cochlear otospongiosis site (photo, C. Hodez and C. Griffaton).

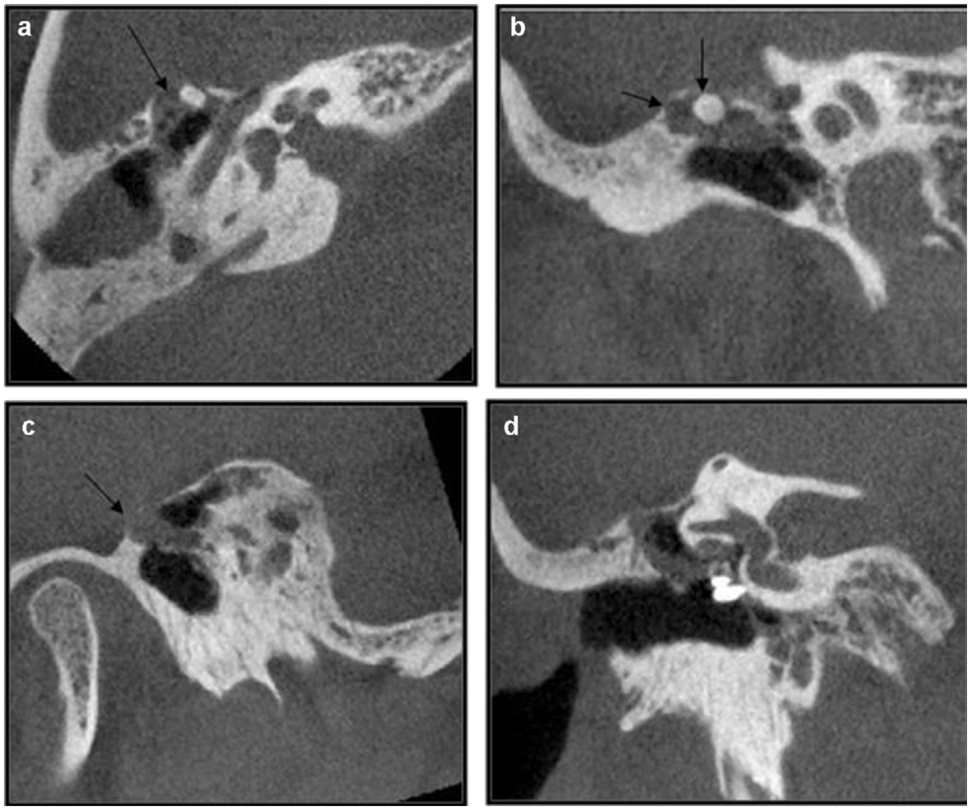

Figure 21 External attical cholesteatoma: multiplanar reconstructions; a: axial slice; b and c: coronal slices; c: sagittal slice; d: partial prosthesis tilt. Good visibility of external attical opacity which, as on CT, appears non-specific but which, associated with inward ossicle chain displacement and attic wall erosion, suggests cholesteatoma. Sagittal incidence, tegmen erosion. Taken from ''Imagerie dento-maxillo-faciale par faisceau conique : ''cone beam'', C. Hodez, P. Bravetti, Sauramps Médical, Montpellier, 2010.
Extract of: Hodez C, Bravetti P. Imagerie dento-maxillo-faciale par faisceau conique: ''cone beam''. Montpellier: Ed. Sauramps Médical; 2010.

Implants

In assessment prior to cochlear implantation, CBCT is effective for cochlear exploration for bone assessment of the thin osseous labyrinthine wall and its lumen, mastoid pneumatization, osseous labyrinth biometry, and facial bone and intrapetrous vascular structure positioning [16]. Postoperative follow-up of cochlear implants (Fig. 22) is

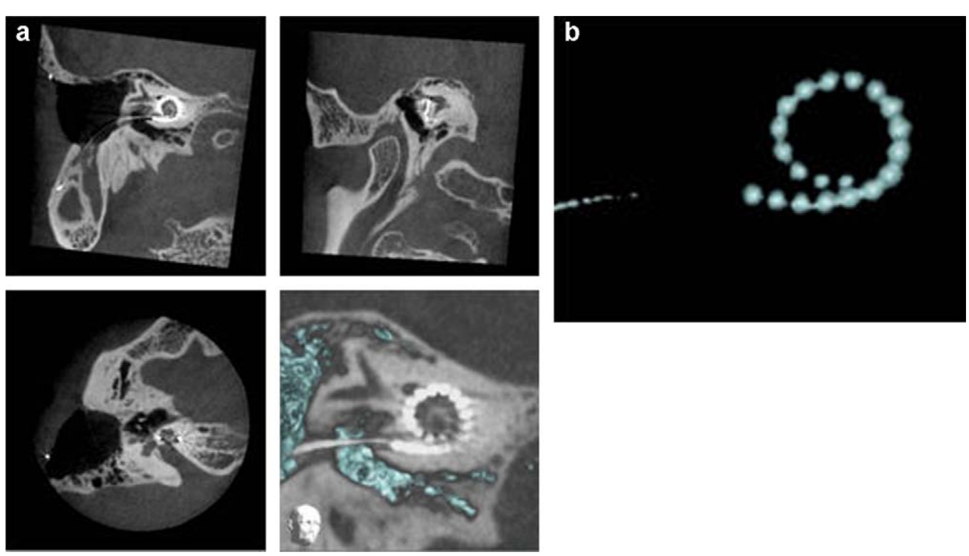

Figure 22 a and b: cochlear implant control. Very moderate metallic artifacts.

more satisfactory on CBCT, due to the lower rate of metallic artifacts. Only the visibility of the spiral lamina remains to be assessed, being hindered by noise in the fine intralabyrinthine bone structures [11].

Peroperatively

CBCT images are compatible with peroperative navigation systems [20].

Conclusion

Cone-beam imaging now rivals or improves on CT data. Full topographic and etiological sinus assessment can be performed using relatively simple and low-cost technology entailing little radiation. Incomparable dental exploration immediately settles the etiological issue in certain types of sinusitis. CBCT will eventually become the gold standard in routine sinus exploration, with techniques involving higher radiation levels and/or costs being reserved for certain pathologies, notably tumor [21].

For the ear, it is an excellent alternative, with a lower radiation level, and more effective if the indication is precise. However, only equipment allowing high resolution with a good signal-to-noise ratio can be used for pars petrosa exploration. As the radiation level is lower than in CT, CBCT is ideal for iterative examination, postoperative follow-up and pediatric exploration.

Study of conductive hearing loss with normal tympanum, exploration for malformation or for cholesteatoma or cholesteatoma surveillance in children old enough to keep still, requires results identical to those of CT, and could greatly benefit from CBCT. In pathologies needing iterative examination, CBCT is to be preferred due to the lower radiation level. Assessment of traumatic bone lesions of the pars petrosa or maxillofacial bones without associated neurologic or cranial lesions can be performed rapidly and easily on CBCT. The technique's limitations, however, need to be borne in mind. It is remarkably good in bone study, with excellent bone/mucosa/air contrast, but its poor density resolution is a drawback for soft-tissue contrast studies. In case of tumoral, septic or hematic soft-tissue infiltration, CT or MRI is mandatory. Likewise, no intravascular contrast medium injection is possible on CBCT.

Disclosure of interest

None.

Acknowledgments

Pr Roger Jankowski was quick to see the interest of cone-beam imaging in ENT exploration, and supported us in our efforts to get to know this technology. He took an active part in the 2010 congress in Nancy (France), and made sure that CBCT would feature on the program of the IESRT congress he is organizing in December 2010. We extend our sincere and friendly acknowledgment.

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