Reading and interpreting CBCT imaging

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ABSTRACT

Introduction: Cone-beam computed tomography (CBCT) is a common auxiliary diagnostic tool in dental practice. The technology requires specific knowledge and training. **Objectives:** This article address basic CBCT concepts, image artifacts hindering quality of examinations, in addition to explaining basic tools necessary for image manipulation. **Methods:** A review was carried out by means of searches on Pubmed database with 19 articles published from 2008 to 2016. **Results:** This paper optimally reviews the entire volume of the image, with the main alterations found in each region.

Keywords: Radiology. Cone-Beam computed tomography. Diagnostic imaging.

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Introduction

Considerable increase in the use of cone-beam computed tomography (CBCT) is present in various areas of Dentistry. Advances in this technology increasingly offers resources and tools to explore, in the best possible way, the images provided. The incessant search for knowledge that governs CBCT, both for the clinical dentist and for the researcher, is evidence that this examination can provide significant data, influencing diagnosis and treatment of diseases. The objective of the present study is to update dentists about this advent and to assist in evaluation and interpretation of volumetric tomographic images; thus elucidating step-by-step manipulation and visualization of images.

Principles of image formation

Unlike spiral computed tomography scanner, the CBCT scanner is compact, which facilitates use and handling by dentists. This piece of equipment has two main components: the source or tube of X-rays, which emits a beam of cone-shaped radiation, and an X-ray detector.

Rotation varies between 10 and 40 seconds. Hundreds of 2D data projections are formed (raw data) and later these images are reconstructed to form a three-dimensional model of the skull. During examination, the X-ray beam and the detector move simultaneously, giving a single 360° turn, around the patient's head, which is stabilized by a support. First, base images are formed at each degree of rotation, similar to cephalograms. At the end of the examination, this sequence of raw data is reconstructed to generate the 3D volumetric image (reconstructions in the three planes: axial, sagittal and coronal), through specific software with a sophisticated algorithm program installed in a conventional computer and coupled to the tomograph.[1,2]

Voxel

From the pixels, the smallest element in a display device, volumetric data set is formed; that is, the three-dimensional image is created. In general, CBCT provides isotropic voxel resolutions (measures equal in all three dimensions). In CBCT, exposure time is proportional to the number of base images and the degree of spatial resolution (voxel size requested). The smaller the voxel size, the greater exposure to radiation and the greater the number of base images. Its dynamic is to capture a series of multiple base images. Due to their projection process, X-rays are not generated during the entire rotation path. In most units, this exposure is pulsed at intervals (also known as frames), so that there is enough time for the signal to be transmitted to the detector area and for storing data after base image creation, thus providing rotation time for the next location or exposure angle. During this interval at which the detector is not ready to receive X-rays, patient exposure is reduced and so is heat buildup during the cycle.[3]

Voxel size

Modern CBCT equipment usually offers the option of choosing voxel size, varying according to the need of each clinical case. The smallest voxel size available today is 75 μm and the largest is 600 μm. The size of voxel is related to spatial resolution; thus, the smaller the voxel, the higher the spatial resolution. Therefore, voxel size may influence diagnosis of examinations that require more details, for example, evaluation of dental trauma and suspected cracks. In contrast, smaller pixels capture fewer X-ray photons, which in turn results in more image noise. When the intention is to have images with good resolution as for evaluation of dental fractures, voxel should be the least value. However, if the region is wide, for example with wide FOV, there is more interference in the image, thus causing restriction when the requirement is detail and good resolution. In order to obtain a satisfactory image, besides voxel size, it is necessary to take into account (inherent) factors such as: focal point size, cone-beam projection geometry, noise quantity, air gap distance, acquisition time, type of sensor, and patient stabilization.[3]

Image detectors

CBCT equipment features two types of detectors: (1) image intensifier / CCD (coupled charge device) with optical fiber image intensifier; (2) silicon flat panel detectors (FPD) (Table 1). The flat panel detector has minimal distortion at image periphery; the units are considered best for generating data sets; the detectors are smaller and have greater ability to distinguish contrast (bit depth). Image intensifiers are larger, more sensitive, more susceptible to magnetic field distortion and require more frequent calibration. However, the latter is used to date because it is more compatible with data set used for the CAD/CAM technology.[2,4,5]

More recently, a third type of detector known as MOSC (metal oxide semiconductor) has come up with new features, such as smaller size compared to others, high resolution, high reading speed and low electronic noise level.[6] Detector technologies differ in size, voxel, noise level, sensitivity, and reading speed.[7]

FOV (field of view)

It corresponds to the scanned field of view. Currently, tomographs have different FOV sizes and vary according to the piece of equipment, being able to present from large FOV (greater than 15 cm), medium FOV (from 10 cm to 15 cm) and small FOV (less than or equal to 10 cm). This means involving from regions of some teeth to the whole face, covering, for example, paranasal sinuses, cervical spine and skull base.[8]

FOV may vary depending on the detector type, beam projection geometry and collimation degree.[3,9] The flat panel, as mentioned above, presents cylindrical FOV, expressed by cylinder height and base diameter. Image enhancers are not presented as cylinders, but are spherical instead. Table 2 presents some examples of dedicated equipment and their variables in relation to FOV size and voxel.[4]

Prescription criteria

Cone-beam tomography provides a higher dose of radiation when compared to radiation doses from other imaging examination devices for dental use, such as teleradiography, panoramic and periapical radiographs. CBCT examination should be recommended only when 2D radiographs do not provide the information necessary for diagnosis and treatment plan. Thus, there must be a reason for its prescription in such a way that the benefits of its accomplishment are superior to the damages caused by radiation to the patient.[7] A project published and named SEDENTEXCT (European Guideline - Link: http://www.sedentexct.eu/file/radiation_protection_172.pdf) has developed evidence-based guidelines on the use of cone-beam computed tomography in

Table 1. Differences between coupled charge device (CCD) and flat panel detectors regarding their main characteristics.

IMAGE INTENSIFIER (CCD)	FLAT PANEL
Larger	Smaller
More sensitive and susceptible to distortion	Minor distortion
Requires constant calibration	No constant calibration required
Spherical	Cylindrical
-----------	Better units to generate dataset
-----------	Greater ability to distinguish contrast (bit depth)

CCD = coupled charge device; FOV = field of view.

Table 2. Specifications of cone-beam tomographers available on the market, according to manufacturers.

Model	Manufacturer	FOV (cm) from maximum to minimum	Voxel minimum (mm³ or micrometer)
3D Acuitomo 170	J Morita (USA)	12x17 to 4x4	0.08
i-Cat	Imaging Sciences International, EUA (Kavo)	17x23 to 8x8	0.125
Prexion 3D, elite	Prexion, INC	5x5 (sole)	0.16/0.11
NewTom 5G	QR srl, Verona, Italy	16x18 to 6x6	0.075
DaVinci D3D	Cefla Dental, Imola, Italy	15x15 to 6x6	0.17
Cranex 3D	Soredex, Milwaukee, WI, USA	6x8 to 6x4	0.085
CS90003D	Carestream Health, Rochester, NY, USA	3,75x5 Stiched 7,5x3,75	0.076 Stiched 0.2
Promax	Planmeca	Ø50 x 55 mm (Ø42 x 50 mm) to Ø230 x 260 mm from a single tooth to the whole face	75 µm to 600 µm

FOV = field of view.

various areas of Dentistry and include justification, optimization and reference criteria for professionals, such as dentists, radiologists, technicians, medical physicists, suppliers and manufacturers.[10]

Image artifacts

Artifacts are structures visualized next to the formed image and which are not present in the real object of which image was taken. They are formed by discrepancies between the actual physical conditions and the mathematical formatting used to make a 3D reconstruction.[11] Artifacts are a reality in CBCT and can often misrepresent the region of interest, making it impossible to see details and negatively influencing information obtained from the examination (Fig 1). One way to reduce the presence of artifacts is to restrict FOV size to the greatest extent possible, so that they are less present in the volume evaluated.

Table 3 shows a summary of the main types of artifacts, followed by theit principle of formation and image characteristic in cone-beam tomography.[11,12,13]

Image management

Image manipulation software basically provides the same tools and is not limited to providing axial, coronal, sagittal planes, line navigation, rotation, slope, panoramic reconstruction, reconstruction for temporomandibular joints (TMJ) evaluation, among others; according to the necessary functions.[3] In the meantime, the layout and presentation forms of these tools vary according to software and manufacturer. The files are saved in DICOM (Digital Imaging and Communication in Medicine) format that has a universal file language or common file format, allowing integration of servers, scanners, printers, workstations and network hardware from different manufacturers.[14]

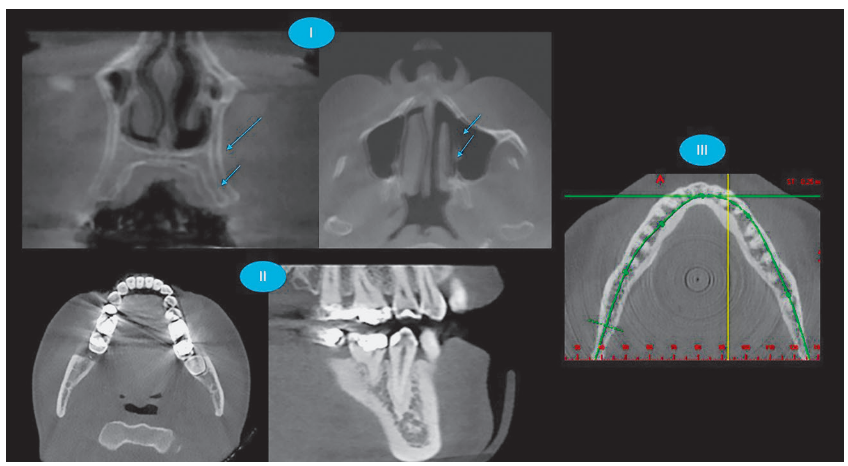

Figure 1. Artifacts. Examples of artifacts found in cone-beam computed tomography (CT) scans: (**I**) motion artifact (arrows indicate duplication of structures); (**II**) artifact of dense material, and (**III**) ring artifact.

Table 3. Possible artifacts found in cone-beam computed tomography images and their characteristics.

Type of artifact	Formation	Image characteristic
Ring artifact	Non-calibration of detectors	“Phantom image" of a ring near its center
Motion artifact	Voluntary and involuntary movements in patient's body	Duplicate image not corresponding to the object
Beam Hardening	Presence of very dense bodies (Examples: implant, amalgam, metallic crown)	Clear and bright stripes
Streaked artifacts or Dark Bands	Sensor does not receive incident photons on its surface due to the presence of very dense material	Dark spots or bands between metal objects of a region
Noise artifact	Absorption variation of X-ray photons	Aspect of granularity
Scattering or dispersion	Photons that are refracted from their original path after interaction with matter	Lines or light rays in the image
Effect artifacts of the cone-beam	X-ray beam divergence	Distortion of extremities

After image taking, the device provides images in its three planes, as follows: axial, coronal and sagittal. As an example, images from i-Cat VisionTM (Kavo) viewer will be used. Before starting the analysis, brightness and contrast should be adjusted to provide a suitable image for evaluation. Other tools, such as a ruler, text box and arrows also help in identifying the structures, mainly for reports and templates.

Understanding the lines

The lines are represented by colors and each represents a plane (axial, coronal and sagittal). By manipulating a line, the ambitious plan will move in accordingly.

When the goal is to evaluate a specific region, the lines must perpendicularly coincide to each other (guide) in such a way that the same structures are visible in the three reformats or three-dimensionally (same point) (Fig 2). As the need arises, one must run the examination to visualize its full extent, always analyzing the three reformats.

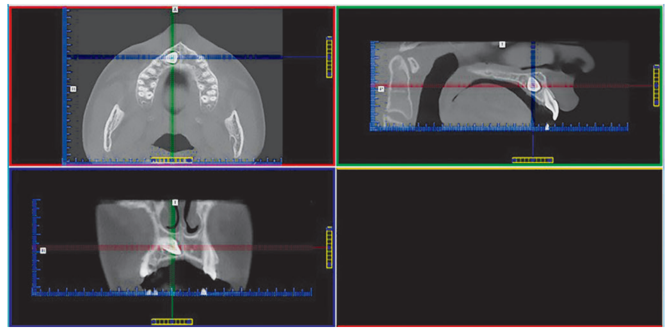

Figure 2. Multiplanar reformatting (MPR): Example of using guide in MPR in i-Cat VisionTM software (Kavo). Note the lines perpendicularly coincide with each other, always pointing to the same structure in all three reformats.

Panoramic reconstruction

To obtain panoramic reconstruction, it is necessary to draw an oblique curve line in the axial plane. The result is a panoramic image and a series of transverse images, also known as parasagittals. To trace this line in the maxilla, the floor of the maxillary sinus can be used as reference, while for the mandible, the mandibular canal is used.

Panoramic reconstruction is a reference to show the location of parasagittal images. It should be thick enough to include the entire arch, so as to prevent any change or structure from not being visualized or identified. To visualize an area of interest in parasagittal slices, it is necessary to give direction, whether to the right or left, with the aid of the reference line located in the panoramic reconstruction (Fig 3).

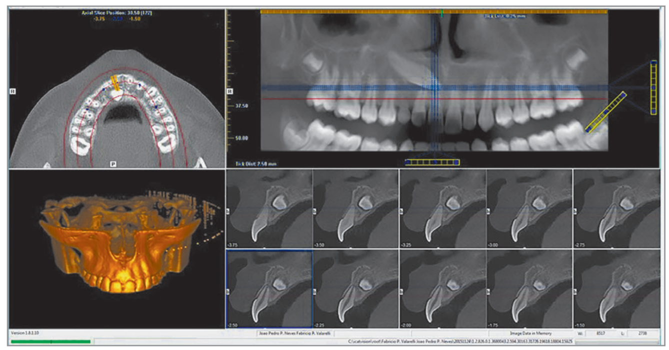

Figure 3. Panoramic reconstruction and Parasagittal slices. Example of panoramic reconstruction and parasagittal images formed from the axial plane in the i-Cat VisionTM software (Kavo). In this specific case, the maxillary right canine tooth and its relation to neighboring teeth can be visualized.

Root evaluation separately

CBCT in Endodontics has been a valuable tool for distinction and individual evaluation of the roots, mainly for investigation of cracks, fractures, periapicopathies and accessory canals. The ability of CBCT to detect apical lesions, especially those that are hidden or that are not possible to visualize in 2D images, confirms the efficacy of its use and consequently safer conduct.[15] Through angulation of planes and synchronization of lines, it is possible to take the cursor to the desired root. In Figure 4, the axial plane was angulated, leaving the corresponding line parallel and over the palatine root, thus, allowing for clearer view in the three planes.

Slice thickness

The thickness of the slice can be increased or thickened (Fig 5). As the layer of thickness increases, many adjacent voxels are added. This view is known as ray sum and allows for generation of simulated projections, such as a teleradiography, Frontal and Panoramic.[1]

3D reconstruction

Allows for visualization of volumetric data. Three-dimensional reconstructions are useful to illustrate the location of impacted teeth, bone fractures, as well as

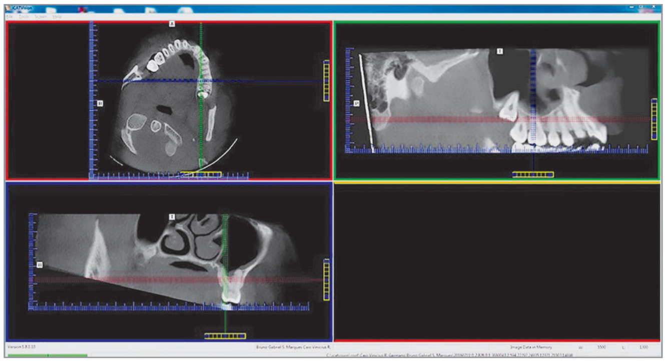

Figure 4. Root evaluation separately. Visualization of the roots separately in the three planes by plane angulation and line synchronization in the i-Cat Vision™ software (Kavo).

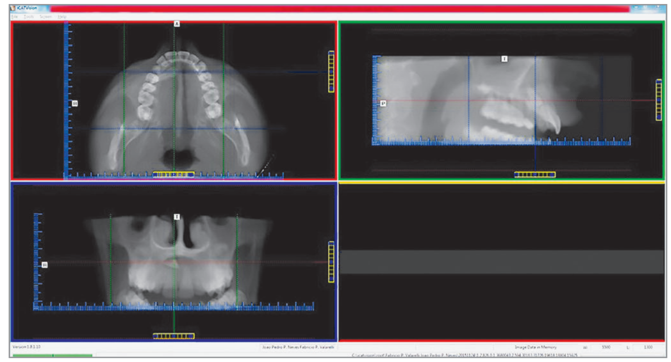

Figure 5. Slice thickness in reformatting. Increasing slice thickness in multiplanar reformattings (MPR), generating different projections (ray sum) in the i-Cat VisionTM software (Kavo).

dystrophic calcifications, and can be worked on an adjustable scale, highlighting hard tissue or hypodense areas, depending on the program. It is important to emphasize that 3D images are not indicated for diagnostic purposes,. Firstly the axial images, then MPR, and finally 3D reconstruction should be evaluated, considering possible loss of 3D image quality, which may result in false results by evaluating it in isolation.[16]

Analysis of structures

Small FOV scanners allow for analysis of only a small region or area of interest. On the other hand, equipment with larger FOVs presents not only the region of interest, but also other adjacent structures. In cases in which the objective of examination is only evaluate the maxilla, for example, FOV variation and the individual anatomy of each patient can provide images of maxillary sinus, nasal fossa and condyles.

The general practitioner is not accustomed to interpreting anatomical structures outside his area of interest or performance. This is critical, since the literature has evinced many incidental findings in the maxillo-mandibular complex.[17,18,19] When considering an examination in which the entire maxillomandibular complex is present, careful analysis of each region should be carried out. It is recommended that the dentist and/or radiologist analyze the entire volume and not just the region of interest.[20]

Dividing by regions or zones

For better clarity and organization of image evaluation, structures can be evaluated by dividing them by zones (including possible changes that we name as lesions of the jaws), especially when image volume covers the whole face. This suggested in the diagrams for visualization of all zones in CBCT examination (Figs 6, 7, 8, 9, 10 and 11).

Methods

A literature review was performed on Pubmed database with the descriptors: "radiology", "cone-beam computed tomography," "diagnosis."

Results

A total of 19 scientific articles was retrieved, following the inclusion criterion of being a literature review or research published from 2008 to 2016, contemplating subjects such as principles of image formation, artifacts, image prescription criteria and analysis of anatomical structures referring to cone-beam tomography.

Discussion

For excellent resolution, mainly to present/display geometry of the isotropic voxel, that is, equal in the three dimensions, cone-beam tomography meets the expectations of dentists, who generally evaluate tissues such as teeth and bones. As a disadvantage of this type of examination, we can mention low soft tissue contrast.[1,2]

How to evaluate examinations separated by regions or zones? As described in the present study, it has been useful and didactic to use similar methodology, with the objective of dividing the examination for a detailed evaluation of each region.[4]

In terms of innovations, modern tomographers have a digital flat panel detector, since the image intensifier is larger, more sensitive, more susceptible to magnetic field distortion, and requires more frequent calibration.[1,6]

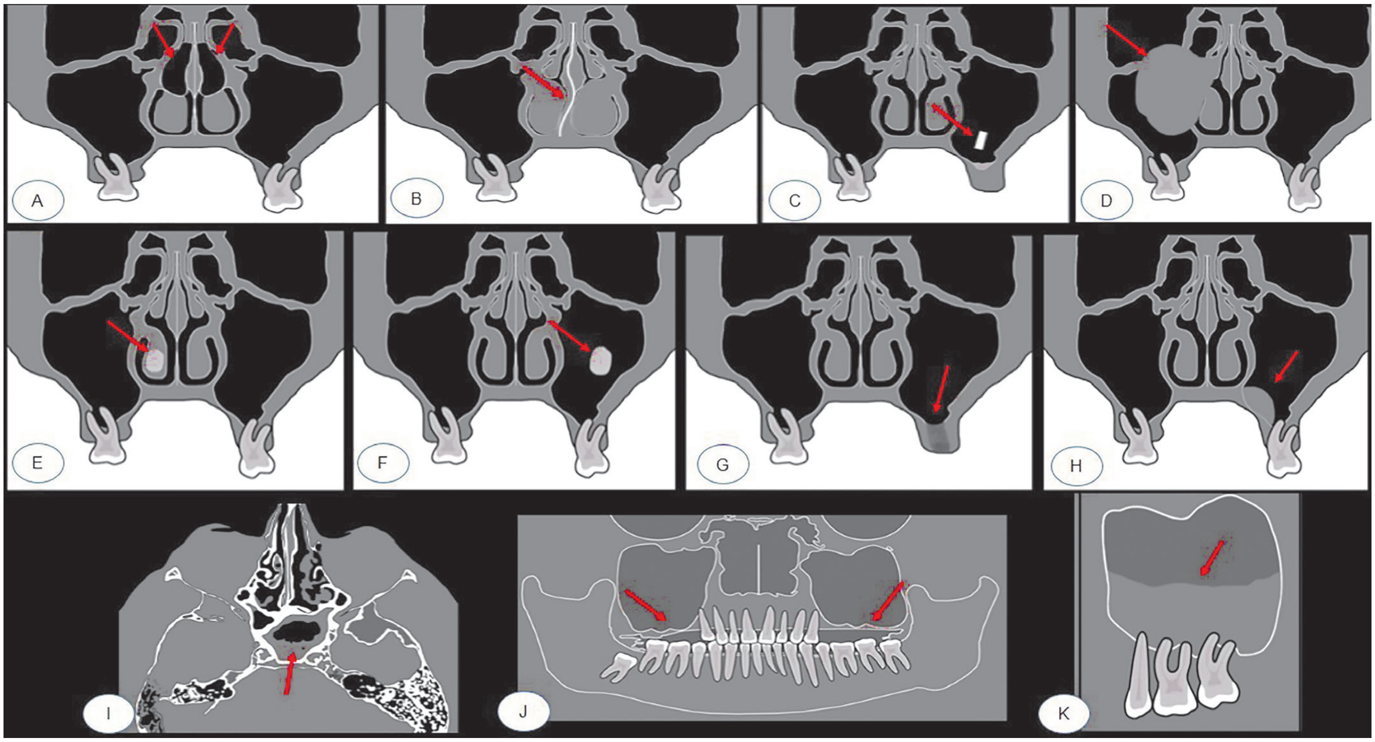

Figure 6. Zone 1: maxillary sinuses and nasal fossa. **a**) Concha bullosa (coronal reconstruction); **b**) septal deviation and corneal hypertrophy (coronal reconstruction); **c**) foreign body in nasal cavity (coronal reconstruction); **d**) mucocele (coronal reconstruction); **e**) rhinolith (coronal reconstruction); **f**) antrolith (coronal reconstruction); **g**) oroantral communication (coronal reconstruction); **h**) mucosal pseudocyst (coronal reconstruction); **i**) thickening of sphenoidal sinus mucosa (axial cut); **j**) alveolar extensions/pneumatization of maxillary sinus (panoramic reconstruction); k) thickening of maxillary sinus mucosa (sagittal reconstruction). Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

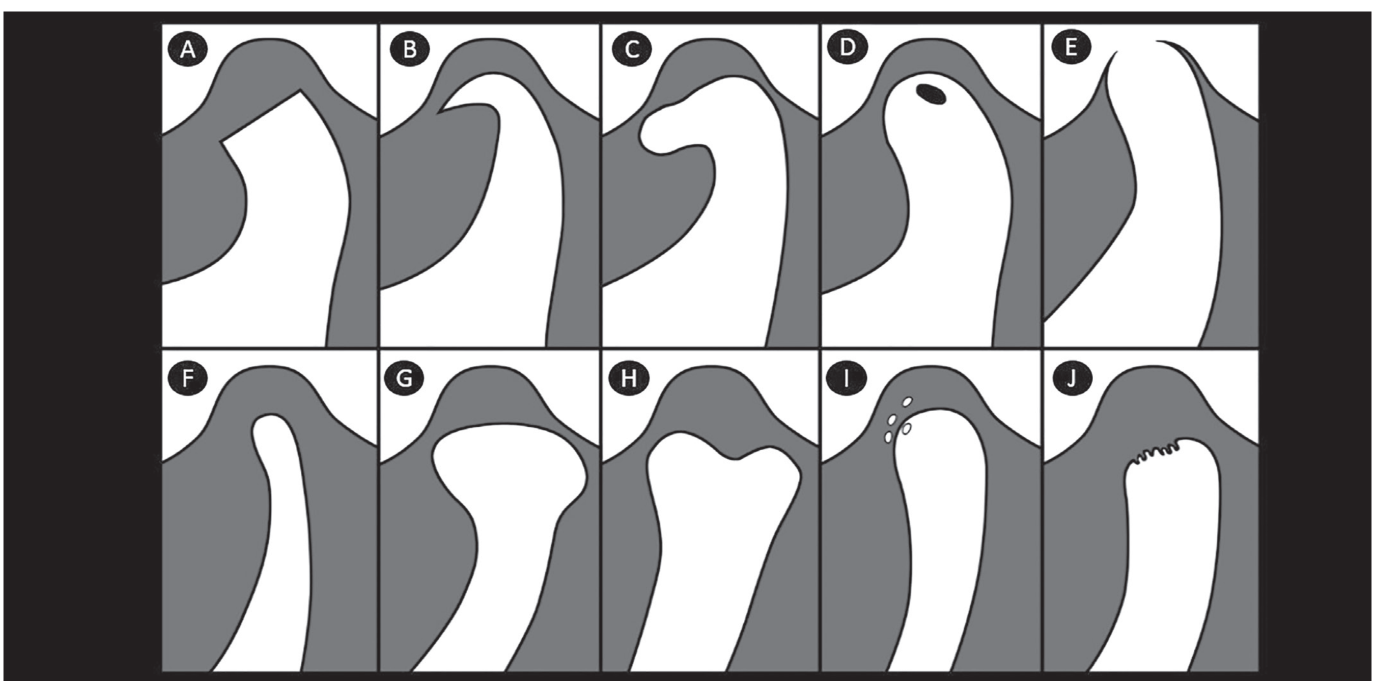

Figure 7. Schemes showing alterations seen in mandible head in sagittal reformatting. Zone 2: TMJ. **a**) planning; **b**) osteophyte; **c**) osteochondroma; **d**) pseudocyst; **e**) ankylosis; **f**) condylar hypoplasia; **g**) condylar hyperplasia; **h**) bifid condyle; **i**) synovial chondromatosis; **j**) erosion/degenerative diseases. Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

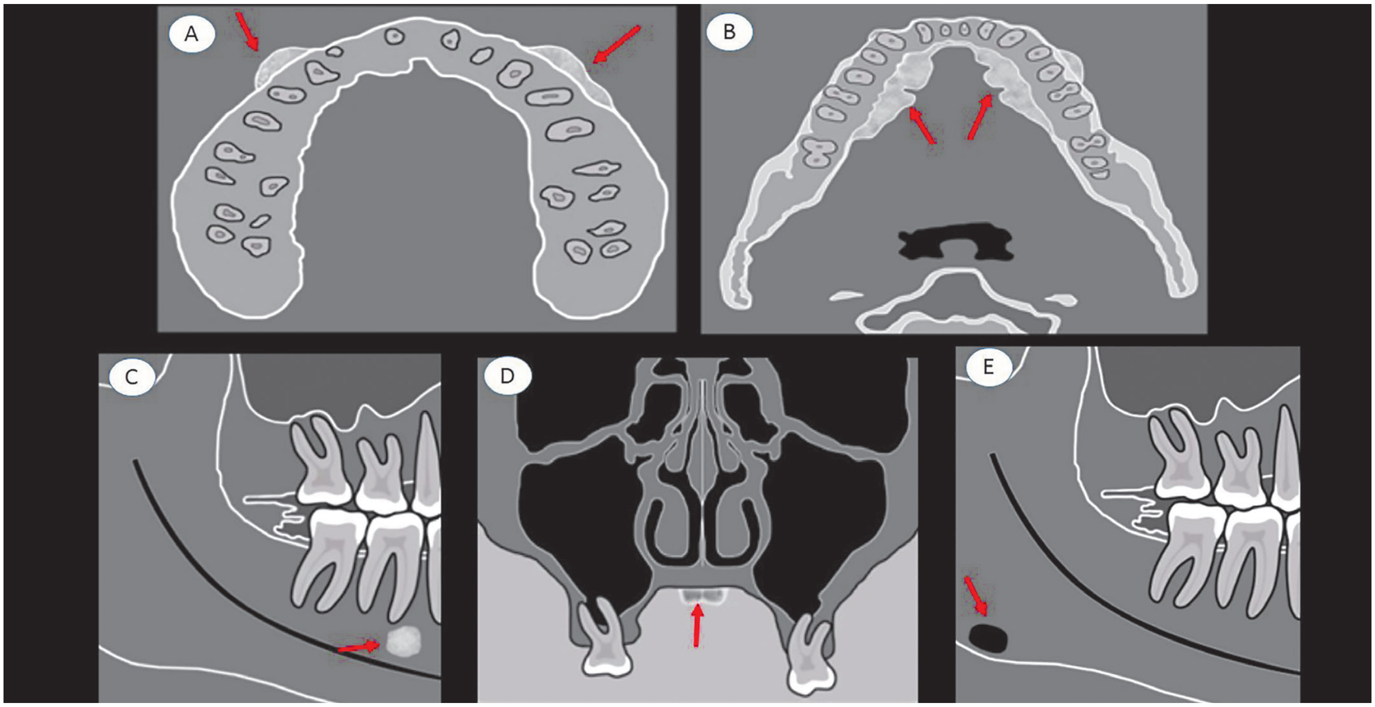

Figure 8. Zone 3: bones. **a**) exostoses (axial reformatting); **b**) mandibular torus (axial reformatting); **c**) bone sclerosis (sagittal reformatting); **d**) palatine torus (coronal reformatting); **e**) Stafne bone cyst (sagittal reformatting). Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

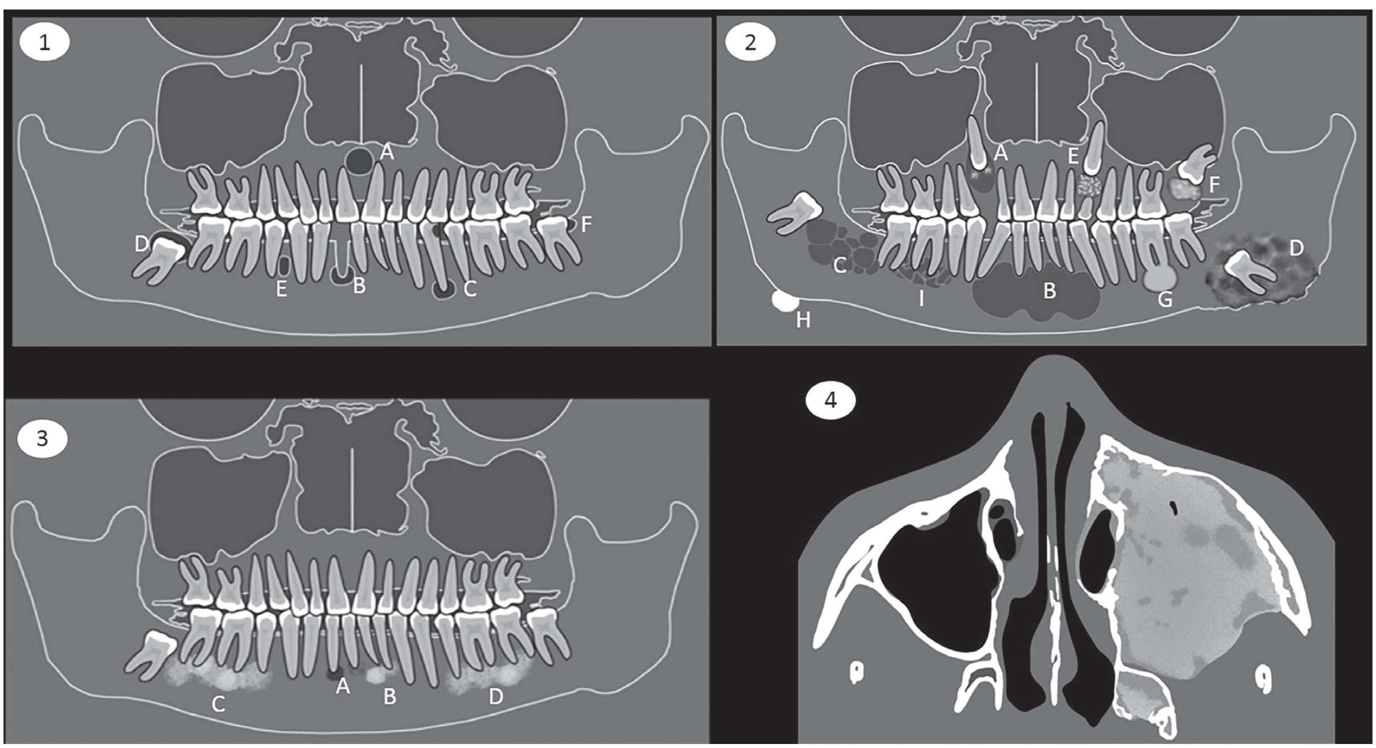

Figure 9. Zone 4: lesions of the jaws. Image 1 (panoramic reconstruction): **a**) nasopalatine duct cyst; **b**) residual cyst; **c**) root cyst; **d**) dentigerous cyst; **e**) lateral periodontal cyst; **f**) paradental cyst. Image 2 (panoramic reconstruction): **a**) adenomatoid odontogenic tumor; **b**) odontogenic keratocystic; **c**) ameloblastoma; **d**) calcifying epithelial odontogenic tumor; **e**) composite odontoma; **f**) complex odontoma; **g**) cementoblastoma; **h**) osteoma; **i**) myxoma. Image 3 (panoramic reconstruction): periapical bone dysplasia in its initial stage (**a**); intermediate stage (**b**); advanced stage (**c** and **d**). Image 4: axial section showing fibrous dysplasia. Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

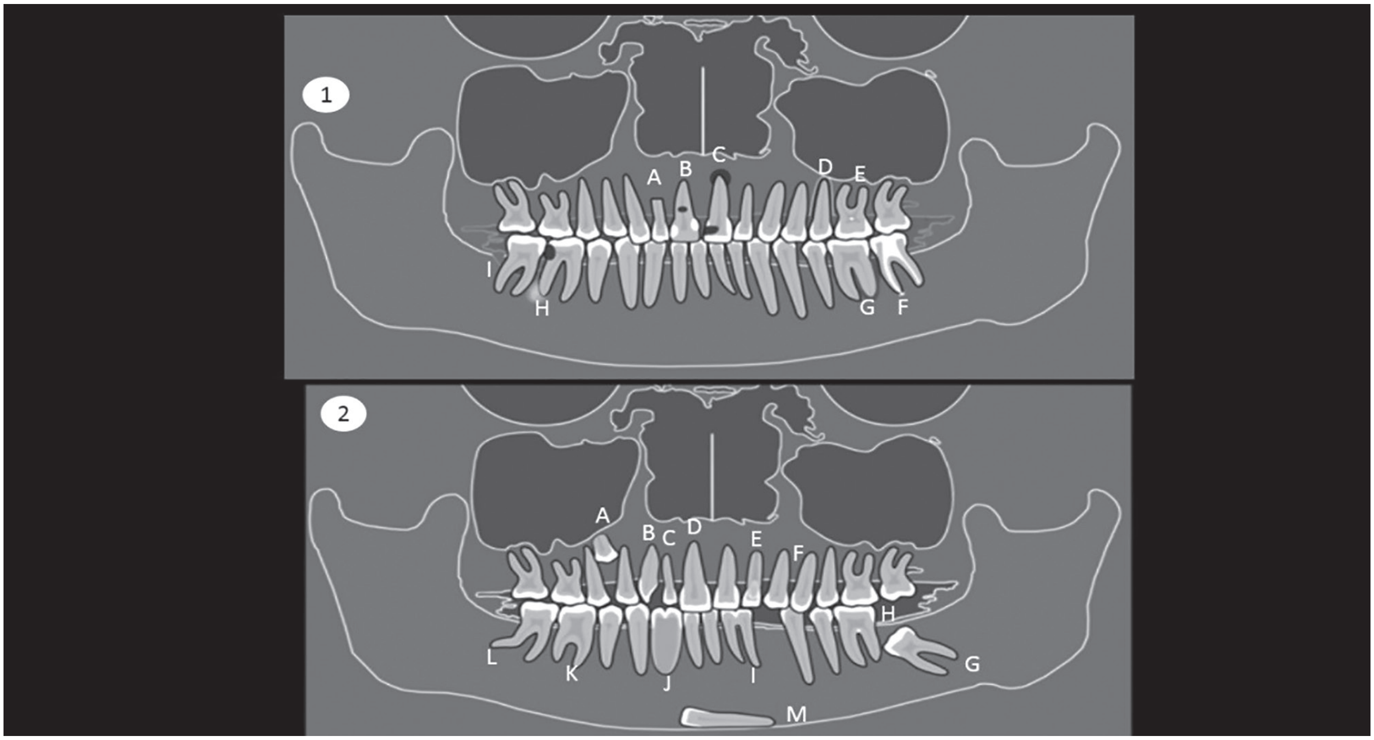

Figure 10. Zone 5. (panoramic reconstructions): teeth. Image 1: **a**) external resorption; **b**) internal resorption; **c**) apical lesion; **d**) increase of apical periodontal space; **e**) pulp calcification; **f**) excess of sealing material; **g**) endoperiodontal lesion; **h**) condensing osteitis; **I**) furcation lesion. Image 2: **a**) supernumerary tooth, **b**) giroversion; **c**) microdontia; **d**) macrodontia; **e**) dens in dente / dens invaginatus; **f**) dental transposition; **g**) retained tooth **h**) enamel pearl; **i**) tooth fusion; **j**) tooth gemination; **k**) taurodontism; **l**) root dilaceration; **m**) transmigration. Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

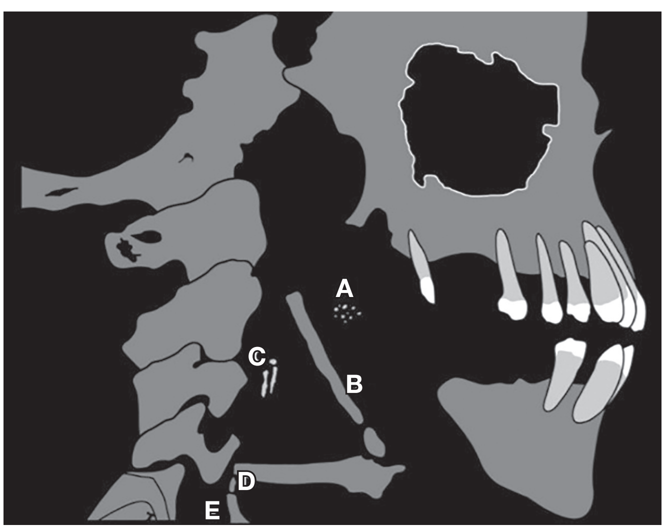

Figure 11. Zone 6: sagittal reconstruction soft tissues. **a**) tonsillolith; **b**) ossification of styloid complex; **c**) calcified carotid artery atheromas; **d**) calcification of triticeous cartilage; **e**) calcification of the superior cornu of the thyroid cartilage. Source: Kazuo. Collaboration: Handem; Lopes; Capelozza.

Artifacts are undoubtedly a reality present in CBCT examinations, movement artifacts can be minimized with head attachment devices and support. A relevant factor is that to acquire high resolution images, for instance, with lower voxel, longer examination time is required for more projections; thus, increasing exposure time and patient's chances of movement during examination. Unfortunately, movement during CBCT taking interferes in all acquired volume, different from conventional tomography, in which it only affects the slices that were compromised at a given moment of the movement.[8] As regards the artifacts of metallic material, or dense material, CBCT is superior (causes fewer artifacts) than conventional tomography.[8]

Reduction of radiation dose to the patient is also due to reduction of FOV used. In a piece of equipment that allows protocols for only one region, with rotation of 180°, the average dose can be reduced up to 45% in relation to the 360° rotation. Pieces of equipment such as Accuitomo 3D model allow for a variety of FOV, from 4 x 4 cm up to 17 x 12 cm.[9] Models of equipment that do not have this range of FOV expose the patient to radiation in often unnecessary regions.

Proper manipulation of software is of paramount importance in the evaluation and diagnosis of images, which is why the dentist and/or radiologist must undergo training of the main tools in order to explore examination in all possible ways, thus making sure to evaluate the entire scanned volume.[4,10]

Conclusion

Cone-beam computed tomography is a complementary imaging examination and does not replace conventional radiographic examinations. The advantage of CBCT is that it allows for three-dimensional image without overlap, distortion or magnification. The main semiological method in examination for diagnosis in Dentistry continues to be clinical examination, associated with histopathological examination whenever necessary. CBCT should be analyzed electronically, so that the whole volume is evaluated. The template performed by the radiologist is restricted to offer images related to the purpose of the examination and in two dimensions, being only an auxiliary tool to dentists, and should not limit examination to templates only.

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