Review Article

Current Status of Dental Cone-Beam Computed Tomography

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Abstract: This article reviews the current situation of CBCT in terms of the indications, the exposure dose to the patient and its reduction, and quality assurance in the use of CBCT. Plenty of articles related to these topics including several guidelines based on the scientific evidence have been published and these cover essentials for consideration in these tasks. Such evidences are helpful for clinicians when considering the application of CBCT, and suggest that clinicians should keep abreast of recent advances in CBCT technology.

Key words: dental, cone-beam CT, indication, exposure dose.

Cone-beam computed tomography (CBCT) systems are a variation of traditional CT systems. The CBCT systems used by dental professionals rotate around the patient, capturing data using a cone-shaped X-ray beam. The data is then used to reconstruct a three-dimensional (3D) image of the dentition (teeth); oral and maxillofacial region (mouth, jaw, and neck); and ears, nose, and throat.¹⁾ CBCT was developed in the late nineties²⁾ and has rapidly gained popularity for imaging osseous structures in the maxillofacial region³⁾ as it has distinct advantages over CT, such as higher spatial resolution^{3,4)} (especially in the longitudinal direction⁵⁾), lower radiation dosage,^{3,6,7)} relatively low cost,³⁾ and technical ease of operation.⁸⁾ Furthermore, CBCT units can be accommodated in dental office settings,^{3,8,9)} unlike CT machines, which require a hospital environment.^{3,8,10)}

CBCT has a wide range of clinical applications; however, certain criteria have to be followed before patients can be advised to undergo CBCT examination. The European Academy of DentoMaxilloFacial Radiology in association with the SEDENTEXCT consortium and the American Dental Association Council on Scientific Affairs has established a set of principles on the use of dental CBCT.^{11,12)} Namely, CBCT examinations must only be recommended for patients

if the benefits outweigh the risks and if the results will provide additional information that result in better patient management.^{11,12)} Considerable thought should be given to the exposure of children and adolescents before prescribing CBCT. Other imaging modalities that provide similar information with less (or no) exposure to radiation should be considered before the decision to use CBCT is made. CBCT examination should be performed only after a history and clinical examination has been made and it should not be used to screen subjects.

During the radiographic examination, a certain amount of radiation is inevitably delivered to patients and populations. The doses from routinely performed dental radiographic procedures are relatively low but the means to reduce patient exposure should be considered based on the ALARA (as low as reasonably achievable) principle. CBCT delivers a relatively higher dosage to patients compared to conventional dental/panoramic radiography. As a result, justification of the procedure is prerequisite in considering an evidence-based method. As such, optimization of the procedure should be performed with the application of diagnostic reference levels (DRLs).¹¹⁾

The purpose of this article is to review the current situation of CBCT in terms of the indications, the exposure dose to the patient and its reduction, and quality

Fig. 1 The CBCT images suggest an extensive radiolucent lesion around the apex of 26, causing mucosal thickening of the maxillary sinus. These findings cannot be visualized on the panoramic image.

assurance in the use of CBCT.

1. Indications in dental practices

In principle, cone-beam CT may supplement or replace conventional dental X-ray imaging techniques such as intraoral or panoramic radiography if the conventional images are unable to adequately capture the needed information.

Dental caries: CBCT has been found to have higher sensitivity in the detection of occlusal caries^{13~15)} than conventional radiography, although no difference was noted between the two modalities in the detection of proximal caries.^{11,16)} In general, the beam hardening and motion-related artefacts limit the usage of CBCT for caries detection and diagnosis.³⁾ Further, radiation dose and cost are higher with CBCT than intraoral periapical radiographs.¹⁷⁾

Periodontics: CBCT with small fields of view (FOVs) allows adequate visualization of the surfaces of infra-bony and furcation defects that cannot be appreciated well on conventional radiographs.^{11,18,19)} One study reported that CBCT also gave a better estimate of alveolar crest height than conventional radiography.²⁰⁾

Endodontics (Figs. 1 and 2): CBCT has been found to be highly beneficial.²¹⁾ For most endodontic applications,

limited volume CBCT is preferred as it provides increased spatial resolution, decreased radiation exposure, a diagnostically acceptable signal-to-noise ratio, and it is time saving as a smaller volume needs to be interpreted.²²⁾ It has been recommended for the following:^{22,11)}

- Assessment of periapical pathologies in subjects in whom conventional radiographs give a negative finding yet clinical signs and symptoms are positive.¹¹⁾

- Identification of potential accessory canals in teeth with suspected complex morphology based on conventional imaging and determination of root curvature.²²⁾

- For diagnosis of both vertical and horizontal root fractures,^{23~26)} one study reported that reconstructed axial views were more effective in confirming root fracture diagnoses than other reconstructed views.²⁷⁾

- For planning of surgical endodontic procedures when the root apices are in close proximity to important anatomical structures.¹¹⁾

- Localization and differentiation of external from internal root resorption or invasive cervical resorption from other conditions.²²⁾

- Intra- or post-operative assessment of endodontic treatment complications, such as overextended root canal obturation material, separated endodontic instruments, calcified canal identification, and localization of per-

Fig. 2 The CBCT images clearly show the radiolucent line suggesting a root fracture. The root fracture is suspected from clinical findings, but is not evident on the panoramic image.

Fig. 3 The mandibular canal is superimposed on the root of the impacted third molar on the panoramic image. The patient was referred for cone-beam CT. The roots appear closed but separated from the canal on CBCT images.

forations.²²⁾

Impacted mandibular third molar (Fig. 3): Cone-beam CT has been found to be far superior to panoramic radiography in assessing the relationship of the mandibular canal with the roots of impacted third molars and also in revealing the number of roots of third molars.²⁸⁾ CBCT should not be used as a routine imaging tool for third molar impactions and must only be used when conventional radiographs suggest a close relationship between a mandibular third molar and the

mandibular canal.¹¹⁾ CBCT has also been found to be superior to panoramic radiography with regard to prediction of exposure of the inferior alveolar nerve.^{29,30)}

Implant planning: Cross-sectional imaging is necessary for implant site assessment and CBCT is recommended as the current method of choice.^{8,11)} CBCT software application in implant planning is more user friendly than CT software. Small FOVs and optimum exposure parameters must be used. CBCT should be considered when the clinical situation indicates a need for

Fig. 4 The osseous changes of the TMJ are suggested on the panoramic image. The CBCT images clearly show the deformity of the condyle and articular fossa.

augmentation procedures before implant placement, such as sinus augmentation, block or particulate bone grafting, ramus or symphysis grafting, etc. CBCT imaging should not be used for the periodic review of clinically asymptomatic implants. CBCT should be considered if implant retrieval is anticipated.

Orthodontics: Multiplanar images of CBCT offer a more accurate identification of cephalometric landmarks.^{31,32} However, CBCT must not be routinely used for this purpose and should be limited to use in patients with complex craniofacial deformity requiring surgical or combined surgical/orthodontic intervention.¹¹ It has been reported that CBCT can precisely detect the position of unerupted teeth (canines), but may not result in better outcomes.¹¹ If a decision has been made to use 3D imaging for the localization of an unerupted tooth, CBCT should be preferred over CT. Currently, CT is widely used for the assessment of cleft palate.¹¹ CBCT has been found to be as effective as CT for the volumetric assessment of bone defects and may therefore be preferred over CT due to the lower patient dose.³³ One study has suggested that CBCT can be used to assess skeletal maturity and that an additional radiograph (hand-wrist radiograph) can be avoided whenever CBCT is considered as an investigative tool for orthodontic patients.³⁴ CBCT should not be used to monitor skeletal

growth.¹¹

Temporomandibular joint (Fig. 4): The ability of CBCT to detect surface osseous changes in the temporomandibular joint (TMJ), such as bony erosions, remodeling, or deformity, is comparable to CT and is thus preferable to CT as it requires less radiation exposure.³⁵ However, before prescribing a CBCT procedure, it must be discerned whether the use of CBCT would benefit the management of the patient or is merely documentary.¹¹

Others: CBCT is accurate in predicting bone involvement in malignancies and is comparable to CT and single-photon emission CT (SPECT).³⁶ CBCT has also been reported to be of value in the detection of accessory foramina in the mandible,^{37,38} osteomyelitis in combination with scintigraphy,³⁹ osteomalacia,⁴⁰ salivary calculus,⁴¹ the diagnosis and treatment planning of clinically present sinusitis,⁴² the identification of maxillofacial and airway anomalies that could interfere with normal breathing,⁴³ in image-guided surgeries,⁴⁴ in predicting post-operative results in mid-face fractures,⁴⁵ and in assessing pterygoid hamulus morphology.⁴⁶

2. Technical aspects of CBCT

Linear and angular measurements have been reported to be sufficiently accurate on CBCT machines,^{47~50} although a few studies have reported an underestimation

Fig. 5 Average effective dose for CBCT devices, divided into groups based on FOV size. Standard deviations are shown for each group. (From Pauwels R et al.: Effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol*, **81**: 267–271, 2012)

of values,⁵¹⁾ with accuracy being more operator dependent than in CT.⁵²⁾ The accuracy of linear intraoral soft-tissue measurements has also been found to be similar to the accuracy of bone measurements.⁵⁰⁾

CBCT acquisition systems currently yield different pixel values for similar bony and soft-tissue structures in different areas of the scanned volume.⁵³⁾ The difference in grey values arises from increased noise level, scattering, and artefacts.⁵⁴⁾ Larger volume CBCT scans may yield more consistent density values.⁵⁵⁾ Caution is essential when pixel values in CBCT are used to estimate bone density at potential implant sites.⁵⁶⁾

CBCT has several advantages over CT in the maxillofacial region, but it does have its limitations. The number of motion-related artefacts is much higher in CBCT than in CT as patients are either in a sitting or standing position during CBCT scans.⁵⁷⁾ Furthermore, the longer scan times in CBCT contribute to artefacts.⁵⁷⁾ In CBCT, a large volume is irradiated during every basis projection, resulting in a high amount of scatter and significantly increasing the image noise.⁵⁷⁾ In addition, the lower energy photons of CBCT units result in a much lower signal-to-noise ratio compared with CT.⁵⁷⁾ CBCT systems have overcome this issue to some extent and exhibit low noise properties.⁵⁾ CBCT devices are generally suitable for the visualization of

high-contrast structures. One study, however, found that certain exposure protocols can be used to depict low-contrast structures or fine details.⁵⁸⁾ As a result of the low signal nature of CBCT imaging, beam hardening can be a significant disadvantage compared to CT.⁵⁹⁾ In contrast, beam hardening associated with dense non-metallic objects is rarely of significance in CT scans of the head and neck region.⁵⁷⁾ Some CBCT units deliver higher radiation dose levels than CT scans of the jaws, when appropriate low-dose CT protocols are used.⁵⁷⁾ Due to the above mentioned disadvantages, Koong⁵⁷⁾ is of the opinion that, for more serious pathologies in the maxillofacial region, CT remains the modality of choice. Dental CBCT can be recommended as a dose-sparing technique in comparison with alternative medical CT scans for common oral and maxillofacial radiographic imaging tasks.⁹⁾

3. Measurement of dose to the patient and reduction in dose

The widespread use of CBCT mandates the assessment of patient radiation dose. Stochastic effects of radiation such as cancer can occur with diagnostic dental radiology, including CBCT.¹¹⁾ Studies have estimated the effective dose and, for small and medium FOVs, it ranges from 11 to 674 μSv ; for large volume CBCT, it ranges from 30 to 1,073 μSv .¹¹⁾ A similar study showed that a distinction was needed between small-, medium-, and large-field CBCT scanners, as shown in Fig. 5, and protocols, as they are applied to different indication groups, the dose received being strongly related to field size. They also mentioned that the dose should always be considered relative to technical and diagnostic image quality, given that image quality requirements differ among patient groups. These doses are generally higher than conventional radiography, but lower than CT.¹¹⁾ Certain dose reduction protocols have been proposed by several researchers. The size and shape of the FOV affect patient doses. Studies have reported that smaller FOVs result in lower patient doses than large FOVs.^{60,61)} It is preferable for CBCT equipment to provide a range of

FOVs so that the clinician can select the smallest possible FOV that sufficiently covers the region of interest.¹¹⁾ However, it has been found that some small FOV CBCT units do not necessarily deliver doses that are lower than some larger FOV units.⁵⁷⁾ The spherical shape of the FOV used by image intensifier-based imaging systems results in increased brain and thyroid exposure in comparison to a cylinder, produced by flat panel detector-based CBCT units. FPDs are more sensitive to X-rays than image intensifiers, thus further reducing patient doses.⁶²⁾ The addition of copper filters results in substantial dose reduction without affecting the quality of the image.⁶³⁾ However, the SEDENTEXCT consortium has recommended further research with regard to this.¹¹⁾ CBCT examinations should use the largest possible voxel size as it has been demonstrated that the use of large voxel size results in significant reduction in patient dose.⁶⁴⁾ The number of basic projection images and the amount of exposure per image also affect patient dose.³⁾ The use of pulsed X-ray sources rather than a continuous source results in lower patient dose.³⁾ Some studies suggest that the use of partial rotation scans in certain clinical situations results in 50% dose reductions and does not significantly alter the image quality.⁶⁵⁾ Thyroid shields may be used if the thyroid gland is within or close to the primary beam.¹¹⁾ The selection of appropriate exposure settings plays a role in limiting doses while maintaining the image quality at acceptable clinical levels. Increases in kilovolts have the potential to reduce dose by reducing the number of low-energy photons in the X-ray beam.¹¹⁾ It has been reported that milliamperes could be reduced in the equipment without a significant loss of image quality.^{66,67)} Kilovoltage and milliamperes should be adjustable on CBCT equipment and must be optimized during use according to the clinical purpose of the examination.¹¹⁾ A reduction in radiation dose can also be achieved by using narrow collimation.⁶⁸⁾ In general, reductions in radiation dose can be achieved by using lower settings of exposure parameters.^{64,68)} Ludlow⁶³⁾ is of the opinion that it is necessary for oral radiologists to work in association with manufacturers and to provide

guidance through research and sound clinical practice in order to ensure that patient dose is kept as minimum as possible.

4. Quality assurance in the use of CBCT

A quality control program consisting of regular checks on the performance of the equipment and patient dose with regard to CBCT systems is required.¹¹⁾ The clinical image quality must also be assessed at regular intervals. The objective of such a program is to ensure that the images obtained are of sufficient diagnostic quality and give minimum exposure to the patient. The advice of a medical physics expert may be sought during the formulation and implementation of a quality control program.¹¹⁾

The equipment must be tested at the time of installation and at regular intervals throughout its life.¹¹⁾ Guidelines for testing dental CBCT equipment have been provided by the SEDENTEXCT project. Some of the tests require specially devised phantoms, which are commercially available. Several CBCT systems also provide a quality assurance phantom with recommendations on the tests that should be performed. The equipment must be thoroughly examined to ensure that all safety features are correctly installed and functioning. The equipment performance parameters, such as X-ray tube output, voltage consistency and accuracy, filtration, exposure time, and radiation field, should be tested. The digital detectors and the reconstruction software should also be tested. The values obtained at the time of installation act as baseline values for routine testing. It is necessary to monitor patient dose at regular intervals and compare it with DRLs.¹¹⁾ A DRL refers to an easily measureable dose quantity that is set by an appropriate regional or national authority for a specific imaging task based on the relevant regional or local data.⁶⁹⁾ Dose quantities that are to be used for the regular assessment of patient dose must be relatively easy to measure in a clinical situation. Although effective dose is usually considered to be the best overall descriptor of patient dose, it cannot be readily measured and a simpler quantity is required

for routine dose audit. In the UK, the Health Protection Agency has proposed the use of DAP (HPA 2010). Some CBCT units already provide this information after each exposure. Alternative proposals have been explored by the SEDENTEXCT team and dose indices based on point measurement within polymethyl methacrylate (PMMA) phantoms have been proposed. An achievable Dose Area Product (DAP) of 250 mGy cm² for CBCT imaging for the placement of an upper first molar implant in a standard adult patient has been recommended.¹¹⁾ A recent study performed on limited-area CBCT units used by 21 dental offices in Tokyo showed that the DAP values ranged from 126.7 to 1476.9 mGycm², depending on the units used, the size of the FOV, and the exposure parameters adopted by the dental offices.⁷⁰⁾ If it is found that the obtained dose quantities are consistently higher than the established DRLs, a review of the procedures and equipment should be undertaken in order to prevent the risk of stochastic effects of radiation.⁶⁹⁾ It is important for the quality of clinical images to be assessed. This may be done by comparison with standard reference images from high-quality CBCT examinations and reject analysis, in which the rate of unsuccessful CBCT examinations is recorded and the reasons for rejection analyzed.¹¹⁾

An increasing number of dentists have come to use technology. Although cone-beam CT technology has advanced rapidly, concerns have been expressed in regard to whether the information acquired with cone-beam CT imaging warrants the additional exposure risk as well as in regard to the level of training, education, and experience required to interpret the cone-beam CT dataset.¹²⁾ The opportunity to review the most recent information should be given by academia and manufacturers.

In conclusion, several guidelines that have been published based on the latest scientific evidence provide essential principles for consideration in the selection of cone-beam CT imaging for individual patient care. These are very helpful for clinicians when considering the application of CBCT. In addition, clinicians should keep

abreast of recent advances in CBCT technology.

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