REVIEW ARTICLE

Oral and Maxillofacial Radiology

Cone-beam computed tomography and the dentist

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Abstract

Although cone-beam computed tomography (CBCT) is just 15 years old, it has revolutionized the practice of dentistry, so much so, there is hardly a dental specialty which has not been affected by this technology. Nevertheless, it presents the dentist with a number of important challenges. An initial steep learning curve must be addressed without unnecessary exposure to the patient. This is particularly important when the patient is a child.

Introduction

Although cone-beam computed tomography (CBCT) is just 15 years old, it has revolutionized the practice of dentistry, so much so, there is hardly a dental specialty which it has not yet affected.

What is cone-beam computed tomography?

Unlike multidetector computed tomography (MDCT; the now standard CT unit used in medicine), CBCT uses a cone beam instead of a fan beam (Figure 1).[1–3] This means that since the cone irradiates a larger volume in a single rotation (nowadays this rotation may be as little as 180°) the radiation dose imparted is much lower than that by a fan beam. Multiple rotations of the fan beam CT are needed to cover the same stretch of patient. MDCT can also achieve this by their multiple arrays of fan beams (X-ray head detector pairs; currently this is as many as 320 pairs) imparting a similar radiation dose, but in a fraction of the time.

CBCT's spatial resolution (image detail) is superior to that of MDCT, between twice and eight-times better. Furthermore, the spatial resolution of CBCT is just as good in all three planes (axial, coronal, and sagittal), whereas medical CT is only optimum in the axial plane. This is because CBCT produces isotropic cuberilles directly from the dataset without going through the voxel middleman (compare Figures 2 and 3). Although the best MDCTs can approach this by a different process the overall better spatial resolution of CBCT has so far not been remotely challenged.

When does cone-beam computed tomography properly complement the work of the dentist?

Osseointegrated implants were first developed by Brånemark and his team half a century ago,[4] since then it has completely transformed prosthodontics. In addition to excellent technical skills, careful assessment of the patient is necessary to ensure that the implant/s and subsequent restoration has the best chance of success. Although osseointegrated implants have achieved a considerable long-term success, as evidenced by a recent American Academy of Osseointegration systematic review,[5] the need for good pre-implant cross-sectional imaging has generally become to be viewed as essential for successful implants. When the bone height is inadequate for implants then grafts can be considered.[6] Table 1 shows that substantial literature on the value of CBCT to the implantologist is only recent:

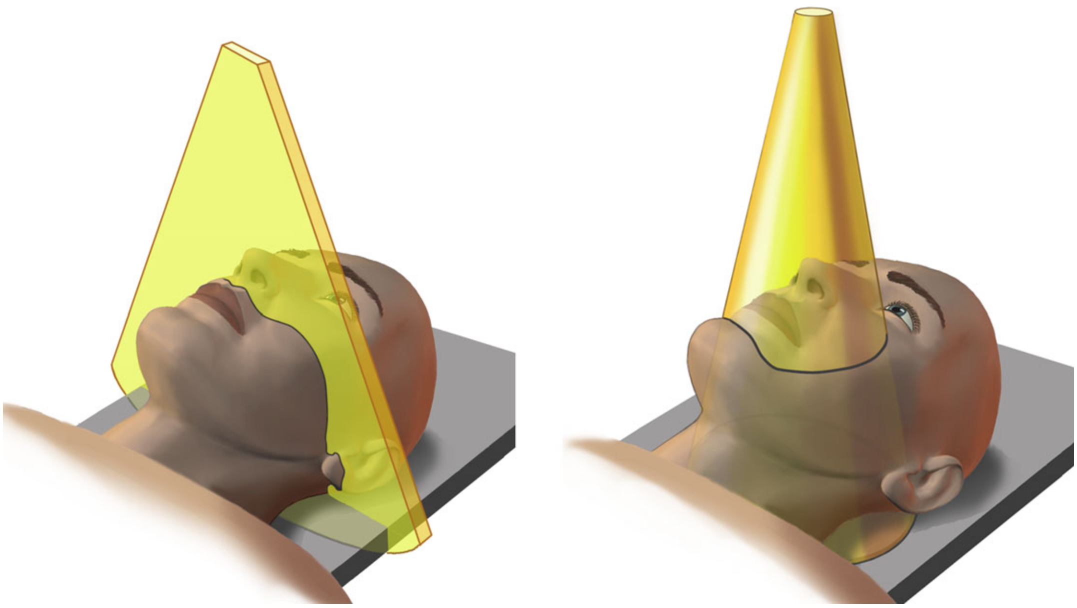

Figure 1. The fan beam upon which medical computed tomography is based interrogates only a slice of tissue, whereas the cone beam of cone-beam computed tomography interogates a three-dimenstional region with in a single 360° rotation (now often less). (Reprinted with permission from MacDonald-Jankowski and Orpe.[22]).

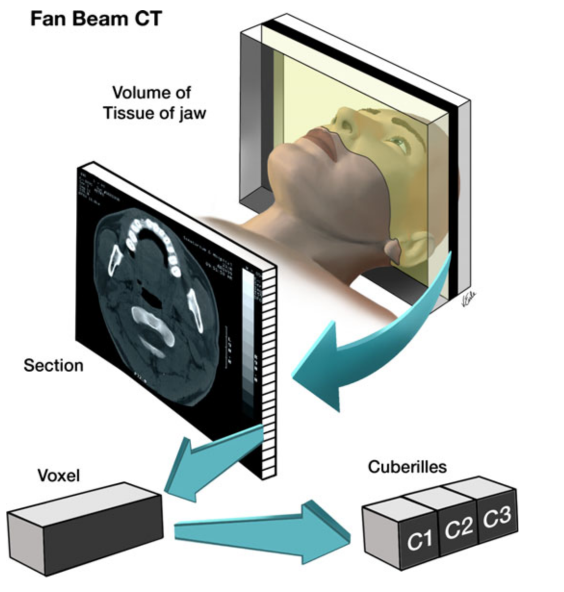

Figure 2. The fan-beam (medical) computed tomography achieved three-dimensional reconstruction by slicing the voxel into cuberilles, each with the same attentuation coefficient as the original voxel. As these cuberilles are arrayed in the *z* axis (patient's long axis) then the spatial resolution would be, as a result, poorer in that axis. (Reprinted with permission from MacDonald-Jankowski and Li.[23]

Hatcher and co-workers[7] first published on CBCT and implants in 2003 and, as Table 1 demonstrates, this was soon followed by a deluge of publications.

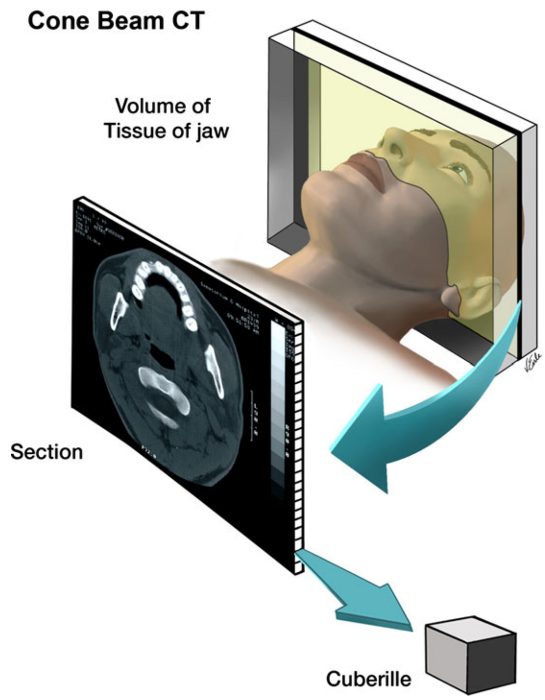

Figure 3. Cone-beam computed tomography recontructs the three-dimensional images by generating cuberilles directly, each with its own attentuation coefficient. This allows three-dimensional reconstructions with better spatial resolution in the *z* axis (in comparison to the fan bean in Figure 2.), in addition to the axial (XY) plane. (Reprinted with permission from MacDonald-Jankowski and Orpe.[22]).

Table 1. Publications on "CBCT" and "Dental Implants"

Year of publication[†]	Number of publications for that year
2003	1
2004	0
2005	0
2006	1
2007	6
2008	14
2009	15
2010	33
2011	44
2012	65
2013	46
2014	70

†Year of first publication, which could be electronic.

CBCT assists the dentist or prosthodontist and his/her surgeon not only to place the implant in sites that allow optimum restoration, but also to identify those at risk of a complication. Wanner and co-authors reported in their systematic review that the five most frequent complications were permanent nerve injury, damage to teeth adjacent to the implant, excessive bleeding in the floor of the mouth, mandibular fracture, and displacement of implants into the maxillary sinus.[8] Inadvertent injury to the mandibular canal and its neurovascular contents are minimized by CBCT, which allows accurate measurement to determine the safe depth of the implant. Excessive bleeding into the floor of the mouth is frequently occasioned by the tearing of the branches of the lingual artery during the implant surgery, as they run through the lingual canals.[6] This is potentially life-threatening. Although, two dozen such reports have, so far, been reported in the literature, they are most likely to represent only the tip of the iceberg.

Stents are now frequently made and provided by the dentist or prosthodontist prior to the CBCT exposure in order to ensure that the implants are placed precisely where they are required.[6] This correct placement also minimizes the chance of the aforementioned complications arising from misplaced implants.

The advent of CBCT units with smaller field-of-views (FOV) and even better spatial resolutions has transformed endodontics. Now the endodontist can find missing (unfilled) canals in previously treated (unsuccessfully) teeth and thus effect a better re-treatment. A retained endodontically-saved natural tooth may serve to obviate many of the

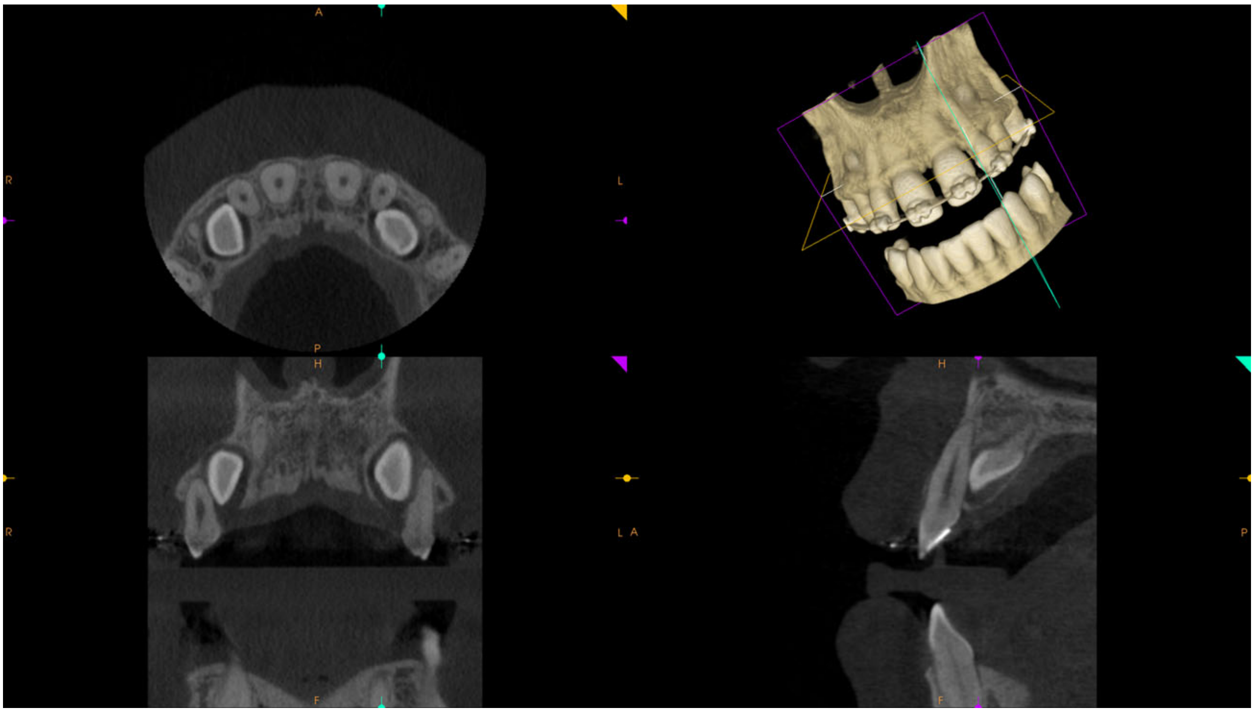

Figure 4. Cone-beam computed tomography (CBCT) of unerupted maxillary canines in intimate relationship to the roots of the fully-erupted lateral incisors. Clockwise, the images are a three-dimensional reconstruction, then sagittal, coronal, and axial reconstructions. The CBCT was prescribed only after the parallax technique revealed that the relationship was likely to be intimate. The CBCT dataset was made of a small/focused field-of view (FOV) and at a high spatial resolution. Such small FOVs are necessary when a high spatial resolution is used in order to minimize the radiation dose. This is particularly important when the patient is a child, such as in this case, in order to reduce the risk of radiation-induced harm to his/her more-rapidly dividing cells. Reprinted with permission from MacDonald D *et al.*[21]

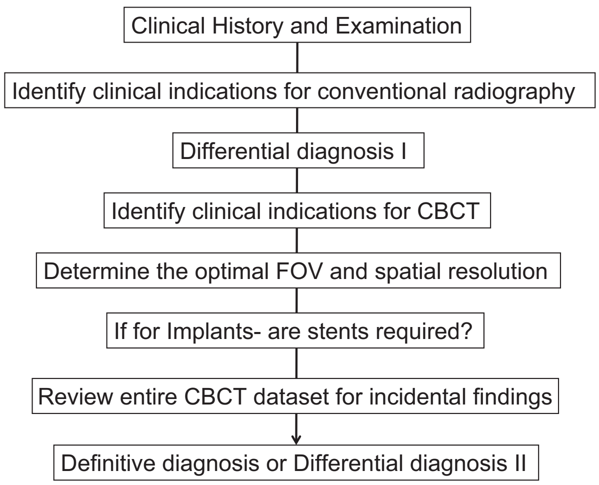

Figure 5. Process for the optimal use of CBCT. Conventional radiography, in addition to producing images of the best spatial resolution (image detail), imparts a significantly lower radiation dose to the patient, especially important for the child patient due to its greater vulnerability to radiation-induced injury. The requirement that the entire image be reviewed, well-established for conventional radiography, is just as relevant for a CBCT dataset.

contra-indications for implants in the elder patient. Indeed the loss of implants is higher than the loss of natural teeth.[9]

Other indications for CBCT are the presurgical assessment of unerupted teeth and intra-osseous pathology, which on clinical examination and conventional dental radiography may have complicated relationships with adjacent teeth (unerupted maxillary canines and an intimate relationship with the apices of erupted incisors [Figure 4]) or other structures (the mandibular canal, submandibular fossa, maxillary sinus, nasopalatine duct or branches of the lingual artery).[6]

CBCT was also shown recently to be useful in the diagnosis and assessment of fibro-osseous lesions affecting the face and jaws. It can also substantially replace medical CT when cross-sectional imaging is required for a lower radiation dose.[10]

What are its downsides?

As CBCT imparts a higher radiation dose than conventional imaging it can only supplement conventional radiography rather than replace it (Figure 5). Figure 6 sets

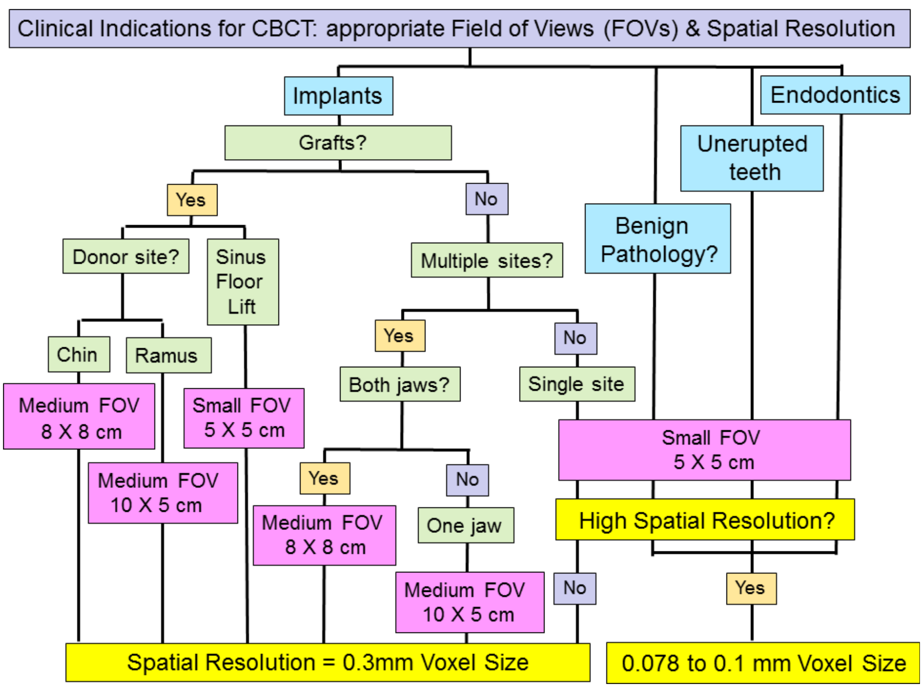

Figure 6. A balance must be struck between minimizing the risk of radiation-induced harm and the need to obtain images of diagnostic quality appropriate for the clinical procedure that is being contemplated. The flowchart reveals that the spatial resolution (degree of detail seen) and size of field-of-view (FOV) vary with clinical indications. Note! The FOVs selected for the flowchart are those available on a Carestream 9300 CBCT unit, other units may offer different FOVs. Nevertheless, use the smallest FOV possible to reduce the radiation dose. The conventional radiological features that suggest 'benign pathology' are set-out in ref. 24. Any lesions that cannot be fully displayed within a small FOV (with better spatial resolution) should be referred to an oral and maxillofacial surgeon or radiologist or to a medical clinic or hospital for a MDCT as intravenous contrast [media] may be required. [Correction added on 14 July 2016, after first online publication: The note in the caption of Figure 6 has been corrected to 'The FOVs selected for the flowchart are those available on a Carestream 9300 CBCT unit, other units may offer different FOVs. Nevertheless, use the smallest FOV possible to reduce the radiation dose', also Figure 6 was updated.]

out the appropriate role that CBCT plays in the diagnostic process of the dental patient. Although this varies with the make and manufacturer,[11] it is on average more like 10 times more than a panoramic radiograph rather than just one or two panoramic radiographs, as is commonly understood.[12] Furthermore, the better the spatial resolution the higher the radiation dose burden imparted.[11] This burden can be reduced, in many modern units, by selecting as small a FOV as possible (see Figure 4).[12]

The size of the FOV is also important in another regard. While the small (5 × 5 cm or smaller) (sometimes called "focused") and medium (8 × 8 cm [Correction added on 14 July 2016, after first online publication: '8 × 8 to 10 × 10 cm' was changed to '8 × 8 cm'.]) FOVs are adequate for imaging the jaws, the large FOV (more-or-less anything in excess of 10 × 10 cm) will include extragnathic areas. These areas, particularly the eyes, brain, and neck (Figure 7), are outside the remit of the dentist.[13] As their anatomy, pathology, and clinical evaluation do not form part of the undergraduate dental curriculum; the dentist is advised to refer large FOV datasets to a radiologist for review. In the meanwhile, the American[14] and European[15,16] Oral/Dental and Maxillofacial Radiology Academies and the American Dental Association[17] have also already published their own guidelines for proper CBCT use.

In 2013, when exposed to a medical CT scan, 680,211 people aged from infancy to 19 years experienced a 24% greater cancer incidence after a mean follow-up period of nearly 10 years.[18] This cancer excess is likely to continue to increase even though this study has been concluded. The authors recommended that "Future CT scans should be limited to situations where there is a definite clinical indication, with every scan optimised to provide a diagnostic CT image at the lowest possible radiation dose." Recently Image Gently in Dentistry guidelines for the appropriate use of CBCT on the child dental patient have reinforced this recommendation.[19]

Children "are more sensitive to radiation (i.e., estimates of their lifetime risk for cancer incidence and mortality per unit dose of ionizing radiation are higher) and they have a longer lifetime for ill effects to develop."[20] Therefore, the dentist needs to have clear clinical indications prior to exposing a child to radiation, and in particular to CBCT investigations.

The potential owner of a CBCT must be aware that there is a wide range of CBCT units currently on the market. Most units are designed to perform one task optimally. Therefore the potential owner must ensure that the protocols of his/her chosen unit are appropriate for his/her patient-base and services s/he provides (it should be noted that not all units are wheelchair accessible).

CBCT units are not easy to use. The dental team requires considerably more training than a day or half a day provided by the vendor/manufacturer upon installation. The vendor/manufacturer training tends to focus more on the software and is frequently very inadequate with regards to mastery of technique. The dental team will need much practice. While it is almost inevitable, especially at the beginning, that the occasional failure may require reimaging (re-exposure) of the patient, this should be the exception, since as-low-as-reasonably-achievable (ALARA) is even more relevant in today's dental practice due to the wide access to CBCT. Ideally, an anatomical head phantom should be used for team training or practising the technique of an unfamiliar program prior to exposing the patient.[21]

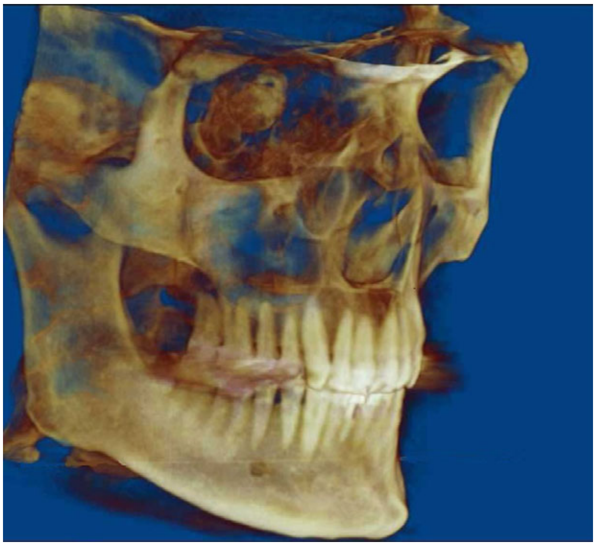

Figure 7. Three-dimensional reconstruction of a cone-beam computed tomography with a large field-of-view (FOV) displaying the eyes, base of the skull (and adjacent cranial cavity) and cervical vertebra, and spinal canal, all of which are outside the maxillofacial complex, the area of competence of the dentally qualified clinician. Although dental professionals with a registerable medical qualification may comment on these extragnathic areas, it is prudent to refer to a medical radiologist who has been trained on head-and-neck radiology. Avoidance of this requirement can be achieved by using an appropriately smaller FOV as set out on Figure 6. (Reprinted with permission from MacDonald;[2] Figure 5.4).

The patient must be stationary for the entire scan. Although most scans by modern machines can be completed in less than 30 sec, the extra time taken to optimally position the patient must also be taken into account. This positioning time will be reduced by the skill and experience of a well-practiced dental team. Furthermore, the nervous patient's fears may be addressed by the use of "dry-run" rotations to develop the patient's confidence prior to doing it for real, when X-rays are generated to produce the image. A facility almost all modern CBCT units have is the generation of a "scout view" at the beginning of the scan. This will allow the operator to determine whether the patient has been optimally positioned prior to proceeding with the full exposure. As the taking of a scout view imparts a fraction of the dose of the overall scan, then the exposure can be terminated preventing unnecessary further exposure of the patient.[21]

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