Cone-Beam Computed Tomography (CBCT) in Dental Practice

Abstract: Cone-beam CT is an exciting development in dental and maxillofacial imaging. This article gives an overview of the subject and discusses some of the implications for dental practitioners.

Clinical Relevance: Dentists should be aware of technological advances that potentially are going to have major implications on their practice. They should have knowledge of the indications, limitations and implications before considering using such equipment. Dent Update 2008; 35: 590-598

Ever since the ‘dental x-ray pioneers’ took the first radiographs of teeth in early 1896, radiology has become an integral component in the assessment of the dental patient. The vast majority of radiographs taken in dental practice are intra-oral, but with an increasing number of extra-oral views being utilized, such as dental panoramic tomography and, to a much lesser extent, cephalography; these latter two views being available, commercially, as combined units.

For most dental practitioners, the use of more advanced imaging modalities, as found in general hospital radiology departments, has been limited as a result of accessibility, cost and radiation dose considerations. Despite these restrictions, there is a requirement in a number of clinical situations for more ‘multiplanar’ imaging. Until recently, this has only been obtainable using computed tomography (CT) or magnetic resonance imaging (MRI) but, with the advent of cone-beam imaging, this facility can now be available within dental practice.

Although cone-beam technology has been around for almost two decades, it is only recently that production costs, including relatively inexpensive but powerful, personal computers, has enabled units to be produced that are affordable for a dental clinic.

Conventional versus cone-beam CT

Conventional CT uses a fan-shaped x-ray beam rotating in a helical fashion around the patient, with the data being acquired by solid state detectors located around the gantry (Figure 1). In most modern scanners, the detectors are arranged in parallel arrays, allowing up to 64 slices to be obtained simultaneously with each rotation. This considerably reduces the scanning time compared to the older single slice acquisition formats. The images obtained are typically ‘axial’ cross-sections through the region of interest, but with associated computer algorithms these can

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Figure 1. Conventional Computed Tomography — fan-shaped x-ray beam rotates around patient as patient passes through gantry. Image slices recorded by a bank of detectors.
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Conversely, cone-beam scanners are based on a cone-shaped beam of x-rays rotating around the object of interest giving a volume of data, using a 2-dimensional extended digital array as an area detector (Figure 2). The technique involves a single 360 degree scan in which the x-ray source and reciprocating area detector synchronously move around the patient’s head, which is stabilized with a head holder. At certain degree intervals, single projection images, known as ‘basis’ images, are acquired. These are similar to lateral cephalometric radiographic images, each slightly offset from one another. This series of basis projection images is referred to as the projection data. Software programmes incorporating sophisticated algorithms, including back-filtered projection, are applied to these image data to generate a 3D volumetric dataset, and can be used to provide primary reconstruction images in three orthogonal planes (axial, sagittal and coronal), as well as 3-dimensionally.¹

Clinical applications of cone-beam imaging

Cone-beam CT is an exciting new addition to the imaging armamentarium which can be utilized to investigate the head and neck. It has the potential to transform practically all aspects of dental imaging. It offers an alternative to the need for complicated interpretative reasoning currently used, for example, in parallax techniques for location of unerupted teeth. For ectopic, palatally placed maxillary canines parallax techniques have been shown to have a sensitivity of 69%, using a vertical technique, and 88% for horizontal parallax, but for buccally displaced canines these sensitivity figures both drop to 63%.² In view of these figures and with the advent of cone-beam imaging, which gives so much more detail, perhaps the dose/benefit ratio needs to be reappraised. The 3-D nature of the data obtained allows easy visualization of structures in the complex maxillofacial environment. The potential scope of clinical applications for cone-beam imaging is vast and currently has been shown to be particularly useful in the following dental and maxillofacial areas:

- Investigation of jaw pathology including cysts, tumours and fibro-osseous lesions;
- Investigation of the paranasal sinuses;
- Investigation of the bony components of the TMJ;
- Pre- and post-implant assessment;
- Orthodontic assessment, both dental development and skeletal base relationship;
- Assessment of wisdom teeth, in particular their relationship to the inferior dental canal;
- Evaluation of facial trauma.

In addition, it provides the capability to visualize anything 3-dimensionally; from anatomical tooth anomalies as, for example, in endodontic cases,²³ to the composition of periodontal defects⁴ (Figures 3-6).

Advantages of cone-beam imaging

Cone-beam imaging is well-matched for the craniofacial area, in
particular for evaluating bone and dental hard tissue. As these units have been custom designed for this region, unlike conventional CT, the software has been specifically produced to simplify obtaining the most useful views using pre-set parameters. In addition, most have been developed to work with other propriety maxillofacial imaging software, such as SimPlant (Materialise, Leuven, Belgium) and Nobel Biocare (Sweden) for implant planning. Also, compared to conventional CT, there are a number of significant advantages.

- Dose reduction: published data for cone-beam CT indicate an effective radiation dose between 0.035 and 0.10 mSv, which is up to a 98% reduction compared to conventional CT (effective dose for CT of mandible and maxilla being 0.4 mSv – Newcastle University Trust Hospitals data*) and equivalent to approximately a full mouth series of periapicals or 3–10 standard dental panoramic tomograms (Table 1).

(*Dose calculated by Julie Willis, Medical Physics Department, Newcastle upon Tyne Hospitals using a programme produced by Imaging performance of CT scanners – www.impactscan.org/ctdosimetry.htm)

- X-ray beam limitation: reducing the size of the irradiated area by collimation of the primary x-ray beam to the area of interest minimizes the radiation dose. Most scanners can be adjusted to scan specific small regions or to include the entire craniofacial complex, depending on the required task.

- Rapid scan times: because all the basis images are acquired in a single rotation, scan time is quick, varying between 10 and 40 seconds. Fast scan times also result in fewer artefacts, such as those due to patient movement. These scan times are comparable to conventional dental panoramic imaging and those of modern helical CT units.

- Image accuracy: the volumetric dataset comprises a 3-D block of smaller cuboid units, known as voxels, each representing a specific degree of x-ray absorption. The size of these voxels determines the resolution of the image. In conventional CT, the voxels are anisotropic, i.e. rectangular cubes, where the longest dimension of the voxel is the axial slice thickness and is determined by slice pitch, a function of gantry motion. Although CT voxel surfaces can be as small as 0.625 mm square, their depth is usually in the order of 1–2 mm. All cone beam units provide voxel resolutions that are isotropic, i.e. equal in all three dimensions. This produces sub-millimetre resolutions (often exceeding the highest grade multi-slice CT) ranging from 0.4 mm to as low as 0.125 mm.¹

- In conventional CT of the oral region, the presence of metallic dental restorations causes a problem due to streak artefact, which can significantly degrade the image.
Cone beam imaging also produces streak artefact but to a much lesser extent and consequently provides superior quality images of oral structures (see below).

**Limitations of cone-beam imaging**

Cone-beam imaging is not in itself a panacea in radiological terms. In fact, its exact role in head and neck imaging has yet to be critically evaluated. The quest to accumulate an evidence-based approach is meeting a number of obstacles. For example, who should collate the evidence and make recommendations for best practice.

- Research into cone-beam imaging has to meet the challenge of rapid changes in both hard- and soft-ware technology, which can render publications outdated before they even get to press.
- The equipment itself is changing in order to meet the clinical requirements reported to manufacturers, who in turn have markets to consider. However, it should not be forgotten that there are intrinsic limitations in the technique which mean, in some circumstances, other forms of dental imaging would be more appropriate. Caries and teeth adjacent to amalgam and other dense prosthetic restorations are not well imaged by cone-beam technology owing to beam hardening and streak artefact. Some units combat this anomaly better than others. Even gutta percha may give rise to streak artefact and appear as dense as amalgam might on conventional CT. This should be borne in mind when assessing a potential site for implants adjacent to root-filled teeth.
- If the clinical question is about lamina dura configuration or bony detail, then the periapical image may provide the answer with a fraction of the radiation dose, both lamina dura and bony detail being superior on periapical radiographs compared to cone-beam.*
- In order to acquire an undistorted image with cone-beam imaging, it is essential that the patient’s head is kept still during the gantry rotation. Obviously, quicker scan times help facilitate this and most machines come with a head positioning and stabilizing device but, as with dental panoramic tomography, patient movement can limit the technique for very young children, those unable to stay still or with movement disorders.
- Interestingly, to those not used to working with 3-D volumes, radiological interpretation can be difficult when using a smaller field of view, as it is easy to become disoriented when scrolling through the images, as points of reference such as normal dental landmarks, or anomalous anatomy can make orientation difficult.
- Cone-beam technology based on an image intensifier may allow the periphery of the image to be distorted.
- To date, cone-beam technology gives little in the way of soft tissue detail and, although newer algorithms have been developed to improve this aspect, it in no way compares to those capable of conventional CT. This, obviously, precludes the technique in the assessment of head

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Radiation Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoral (F speed, rectangular collimator)</td>
<td>0.001 mSv</td>
</tr>
<tr>
<td>Intraoral (E speed, round collimator)</td>
<td>0.004 mSv</td>
</tr>
<tr>
<td>Full Mouth Set (E speed, round collimator)</td>
<td>0.080 mSv</td>
</tr>
<tr>
<td>Lateral Ceph (F speed, rare earth screen)</td>
<td>0.002 mSv</td>
</tr>
<tr>
<td>DPT (F speed, rare earth screen)</td>
<td>0.015 mSv</td>
</tr>
<tr>
<td>Cone Beam CT - both jaws</td>
<td>0.068 mSv</td>
</tr>
<tr>
<td>Hospital CT Scan - both jaws</td>
<td>0.6 mSv</td>
</tr>
</tbody>
</table>

**Figure 7.** Head restraint in an early model of the Morita, Accuitomo CBCT. Facial soft tissue profile is distorted by this arrangement.

**Figure 8.** Setting up the patient in a Promax, Planmeca 3D CBCT scanner. Note the flat panel image receptor to the right of the picture.

**Figure 9.** Patient being set up in Galileos (Sirona) scanner. Note the bulky image intensifier (receptor) to the right of the picture.

Table 1. Typical doses from various dental radiological procedures.
and neck malignancy where evaluating the soft tissue extent of the lesion is crucial. Cancer staging will continue to be performed with conventional CT and/or MRI supplemented with newer imaging offered by CT/PET scanning in the near future (Figures 7–19).

Some technical comparisons for CBCT units currently available are given in Table 2.

Discussion

Cone-beam imaging, sometimes referred to as digital volume tomography, is one of the most exciting developments in dental and maxillofacial radiology and, owing to its versatility, will almost certainly become an increasingly popular form of imaging available in dental practice. As a result, more manufacturers will doubtless develop units with the result that purchase costs will almost certainly reduce. Some manufacturers are already producing hybrid units combining dental panoramic tomography with a limited cone-beam facility incorporated.

However, although cone-beam imaging allows images to be displayed in a variety of formats, the interpretation of volumetric datasets, particularly when it involves large areas, means more than simply the generation of 3-D images. Interpretation demands an understanding of the spatial relations of bony anatomical elements and a comprehensive pathological knowledge of the various maxillofacial structures involved. Obviously, this information can extend beyond purely the dento-alveolar complex. Currently, any dental practitioner can purchase and operate a cone-beam unit. There is mounting concern among oral and maxillofacial radiologists, based on issues of quality and patient safety, that interpretation of extended field of view diagnostic imaging studies using cone-beam should not be performed by dentists with inadequate training and experience. The obvious potential for missed occult pathology with these units does, if nothing else, increase the risk of litigation. A recent study using CBCT showed 24.6% had incidental findings. It would be in the patient’s best interest that an imaging specialist with optimal knowledge of this area view the total volume obtained during image acquisition. Similar recommendations have been made internationally, where the need for a specialist radiological report is advised for all ‘larger volume’ images. In addition, the radiological report can give added value, often with that ‘extra insight’ into matters dental where an incidental radiological finding could make a major difference to treatment planning.

The problem is exacerbated by the fact that cone-beam imaging uses ionizing radiation doses exceeding any other existing form of dental imaging. The basic tenets of ALARA and maximizing the benefit/risk ratio to the patient still apply when selecting cases for imaging.

With increasing potential use of cone-beam imaging for a variety of clinical situations, guidelines need to be developed indicating best practice. Dental undergraduates will require training in the interpretation and limitations of cone-beam CT. The ability to export data into software packages, such as Simplant/Materialise and Nobel Biocare and their manipulation,
Table 2. Characteristics of some CBCTs on the market – (Reproduced by kind permission of Prof. R Jacobs).

<table>
<thead>
<tr>
<th>CBCT device</th>
<th>Company</th>
<th>Dimensions (mm)</th>
<th>kV</th>
<th>mA</th>
<th>ST (s)</th>
<th>Voxel (mm)</th>
<th>RT</th>
<th>Object size (mm)</th>
<th>detector type</th>
<th>FS (mm)</th>
<th>GS (bit)</th>
<th>Pat. Pos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Accuitomo</td>
<td>J. Morita, Japan</td>
<td>2000 x 1600 x 850</td>
<td>60-80</td>
<td>1-10</td>
<td>18</td>
<td>0.125</td>
<td>&lt; 5'</td>
<td>40x40,60x60</td>
<td>FPD</td>
<td>0.5x0.5</td>
<td>12</td>
<td>sea</td>
</tr>
<tr>
<td>i-CAT&lt;sup&gt;®&lt;/sup&gt;</td>
<td>Imaging Sciences Int., USA</td>
<td>1830 x 910 x 1120</td>
<td>120</td>
<td>3-8</td>
<td>10,20,40</td>
<td>0.4 (0.2)</td>
<td>2-10'</td>
<td>160x130(220)</td>
<td>Am Si FPD</td>
<td>0.5x0.5</td>
<td>14</td>
<td>sea</td>
</tr>
<tr>
<td>ProMax 3D</td>
<td>Planmeca, Finland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cal CMOS FPD</td>
<td>0.5</td>
<td>12</td>
<td>sta</td>
</tr>
<tr>
<td>3D Panoramic</td>
<td>Asahi Roentgen, Japan</td>
<td>1600 x 2020 x 1973</td>
<td>60-110</td>
<td>2-15</td>
<td>17</td>
<td>0.1-0.39</td>
<td>/</td>
<td>51x51,200x179</td>
<td>/</td>
<td>0.6x0.6</td>
<td>/</td>
<td>sea</td>
</tr>
<tr>
<td>Picasso</td>
<td>E. Wob technology, Korea</td>
<td>1830 x 1393 x 833</td>
<td>40-80</td>
<td>2-10</td>
<td>15</td>
<td>0.1</td>
<td>29'</td>
<td>120x70</td>
<td>FPD</td>
<td>0.4x0.49</td>
<td>/</td>
<td>sta</td>
</tr>
<tr>
<td>Ilium</td>
<td>Kodak’s Dental Systems</td>
<td>2169 x 1668 x 1967</td>
<td>120</td>
<td>1-3.8</td>
<td>20-40</td>
<td>0.09-0.4</td>
<td>&gt; 2.5'</td>
<td>190x2400</td>
<td>Am. Si. FPD</td>
<td>0.3</td>
<td>14</td>
<td>sea</td>
</tr>
<tr>
<td>Galileos</td>
<td>Sirona, Germany</td>
<td>2250 x 1500 x 1900</td>
<td>85</td>
<td>5-7</td>
<td>14</td>
<td>0.15-0.3</td>
<td>4.5'</td>
<td>15x15x15</td>
<td>CCD</td>
<td>/</td>
<td>/</td>
<td>sea/sta</td>
</tr>
<tr>
<td>Dental CBCT</td>
<td>Carestream, USA</td>
<td>1170 x 1570 x 1925</td>
<td>90</td>
<td>4</td>
<td>19.37</td>
<td>0.1</td>
<td>2'</td>
<td>81x78</td>
<td>Cal FPD</td>
<td>0.2</td>
<td>/</td>
<td>sea</td>
</tr>
<tr>
<td>3D Mercury</td>
<td>Hitachi Medical, Japan</td>
<td>2250 x 1980 x 1900</td>
<td>60-120</td>
<td>10-15</td>
<td>9.5</td>
<td>0.1-0.4</td>
<td>5</td>
<td>220,180,120</td>
<td>CCD</td>
<td>/</td>
<td>12</td>
<td>sea</td>
</tr>
<tr>
<td>CB throne</td>
<td>Hitachi Medical, Japan</td>
<td>1800 x 1600</td>
<td>120</td>
<td>15</td>
<td>9.6</td>
<td>0.1-0.2</td>
<td>/</td>
<td>170,100</td>
<td>CCD</td>
<td>/</td>
<td>12</td>
<td>sea</td>
</tr>
<tr>
<td>NewTom 3G</td>
<td>OR. Italy</td>
<td>1600 x 2500</td>
<td>110</td>
<td>&lt;15</td>
<td>36</td>
<td>0.16-0.42</td>
<td>/</td>
<td>100,150,200</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>lay</td>
</tr>
<tr>
<td>Scannora 3D</td>
<td>Soredex, Finland</td>
<td>1963 x 1541 x 1100</td>
<td>65-85</td>
<td>10-20</td>
<td>0.15-0.35</td>
<td>1-3'</td>
<td>124 x 124</td>
<td>CCD</td>
<td>0.4</td>
<td>/</td>
<td>sea</td>
<td></td>
</tr>
<tr>
<td>Kavo 3D</td>
<td>Kavo, Germany</td>
<td>1830 x 1160 x 1220</td>
<td>90-120</td>
<td>3-8</td>
<td>8,5-24</td>
<td>0.12-0.4</td>
<td>1'</td>
<td>80x80,230x170</td>
<td>Am. Si. FPD</td>
<td>0.5</td>
<td>14</td>
<td>sea</td>
</tr>
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</table>

Figure 14. Small field of view image acquired using the Accuitomo CBCT scanner. Orientation can be difficult with these scanners. Scrolling through the image volume helps however, if the normal tooth configuration is absent, interpretation can be challenging. This view shows a heavily infected root configuration in a partially root treated |7| (palatal root contains a gutta percha point).

Figure 15. i-Cat CBCT interface which delivers the volume in coronal (top left), sagittal (top right) and axial planes (bottom left section).
should also form part of postgraduate teaching curricula, building on an undergraduate exposure to this modality.

As the General Dental Council has made it a statutory requirement for dental practitioners to undertake training in radiology as a component of continuing professional development, perhaps this should be extended to include specific training for those who are either currently using, or are embarking on using, this newer technology. In some countries, such as Norway, specific training for this modality is already a mandatory requirement.

With regard to obtaining specialist radiological reports and opinions, Tele-dentistry, whereby images can be electronically sent to imaging centres of excellence, would allow ease of access to specialist advice, and any dental practitioner contemplating purchasing a cone-beam CT unit should consider such a liaison. Image files can be quite large and protocols would need to be agreed as to what data are sent.

**Conclusions**

Cone-beam CT is almost certainly going to revolutionize dental radiology and impact on almost all aspects of dental practice. As a consequence, many dental practitioners will be considering purchasing this type of imaging equipment, but should take into account the potential implications of imaging a large area of craniofacial anatomy. If considering obtaining a unit with an extended field of view, ie including more than purely the dento-alveolar region, liaison with a specialist in oral and maxillofacial imaging would be recommended.

**Acknowledgements**

The authors would like to thank Professor R Jacobs, Leuven, Dr C Politis, Genk and Dr P Collaert, Leuven, Belgium for their valuable assistance in allowing access to their units and providing material for this paper. We would also like to thank IDT Dental Products Ltd, London, UK for allowing us to use the material in Table 1 and for Figure 1.

The following Cone-beam CT units have been referred to in this paper:
- Accuitomo – J Morita USA, Inc;
- NewTom 3G – AFP Imaging Corporation;
- Promax 3D – Planmeca, Helsinki, Finland;
- i-Cat – Imaging Sciences International, USA;

Figure 16. (a) Coronal section through base of skull. (b) Axial section through skull. These scans show part of the volume obtained in coronal and axial section when the primary aim of imaging was to see the TMJ. Note the normal detail of the middle and inner ear structures. Pathology in these areas could easily be missed.

Figure 17. Conventional non-contrast CT scan of base of skull area with erosion of right foramen ovale due to a malignant process (arrow).

Figure 18. Axial section, conventional CT scan in which a nasopharyngeal mass is located in the right fossa of Rosenmüller (arrow). It effaces the normal airway shadow and requires further investigation. This type of general distortion in soft tissue outline could be picked up on CBCT.

Figure 19. Axial section, conventional CT demonstrating a mass in the nasopharynx which erodes the nasal bones and effaces the normal air pattern of the airway and the maxillary sinuses (arrow). This would be evident on CBCT and should not be missed.
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- Galileos – Sirona Dental Systems, Bensheim, Germany.

References

Relevant websites
- http://www.medical-image-processing.info/MVE/
- http://www.conebeam.com/
- http://www.qrverona.it/htm/distributors.htm
- http://www.vatech.co.kr/_eng/
- http://www.yottalook.com/
- http://www.orad.org/
- http://ddsdx.uthscsa.edu/dig/itdesc.html
- http://www.medical-image-processing.info/MVE/
- http://www.medical-image-processing.info/MVE/
- http://www.conebeam.com/
- http://www.qrverona.it/htm/distributors.htm
- http://www.vatech.co.kr/_eng/
- http://www.yottalook.com/
- http://www.orad.org/
- http://ddsdx.uthscsa.edu/dig/itdesc.html
- http://www.medical-image-processing.info/MVE/

Book Review

The authors should be congratulated for packing so much practical information about evidence-based dentistry into this well structured, easy-to-read book. This book explains how to apply evidence-based decision-making to everyday practice using a selection of commonly encountered dental clinical scenarios. The inclusion of these clinical scenarios brings the relevance and application of the key processes of an evidence-based approach to clinical decision-making into vivid immediacy. The information is clearly and logically presented throughout with a good mix of text, tables, boxes and practical clinical examples, making this both user friendly and also highly instructive.

The book begins by offering an overview of evidence-based dentistry and details a hierarchy of sources of evidence to answer clinical problems. Evidence-based guidelines, Cochrane reviews, systematic reviews and individual studies are discussed, with a comprehensive section on how to perform Medline searches using PubMed. There are easy to understand, comprehensive chapters on how to appraise critically randomized controlled trials, cohort, diagnostic and qualitative studies. These will assist readers in evaluating research papers and then deciding whether the findings are relevant and useful for the care of their own patients. There are valuable sections towards the end of the book which advise clinicians on keeping up-to-date and highlight sources of information which can deliver practical advice for accessing the best evidence quickly and effectively. The inclusion of a glossary of research terminology is very helpful.

Written by well known authorities in this exciting field of dentistry, this book serves as an excellent, practical guide to understanding the principles of evidence-based dentistry and how to apply these to everyday practice. This book is indispensable for dental professionals, at both an undergraduate and postgraduate level, who require a firm grounding in this increasingly important subject area.

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