Applications of CBCT in dental practice: A review of the literature

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This article reviews the various clinical applications of cone beam computed tomography (CBCT). A literature search was conducted via PubMed for publications related to dental applications of CBCT published between January 1998 and June 15, 2010. The search revealed a total of 540 articles, 129 of which were clinically relevant and analyzed in detail. A literature review demonstrated that CBCT has been utilized for oral and maxillofacial surgery, endodontics, implantology, orthodontics, temporomandibular joint dysfunction, periodontics, and restorative and forensic dentistry. This literature review showed that the different indications for CBCT are governed by the needs of the specific dental discipline and the type of procedure performed.

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Two-dimensional (2D) imaging modalities have been used in dentistry since the first intraoral radiograph was obtained in 1896. Since then, dental imaging techniques have advanced with the introduction of tomography and panoramic imaging. Tomography made it possible to isolate areas of interest within the scope of a radiographic examination, while panoramic imaging utilizes principles of tomography, making it possible to visualize the maxillofacial structures in a single comprehensive image. More recent advances in digital diagnostic imaging have meant lower radiation doses and faster processing times without affecting the diagnostic quality of the intraoral or panoramic images. However, 2D images possess unique inherent limitations (including magnification, distortion, and superimposition) that can make it possible to misrepresent structures. Cone beam computed tomography (CBCT) is capable of producing three-dimensional (3D) images that can guide diagnosis, treatment, and follow-up.

Introduced in 1998 for dentoalveolar imaging, CBCT generates 3D data at a lower cost and with lower absorbed doses of radiation than conventional CT. CBCT’s imaging technique is based on a cone-shaped X-ray beam that is centered on a 2D detector, which offers the advantages of a higher rate of acquisition; unlike conventional CT, a parallel shift of the detector system during rotation is not required, which results in a more efficient use of tube power. The cone-shaped beam rotates once around the object (in this case, the patient’s head and neck), capable of producing hundreds of 2D images of a defined anatomical volume rather than the slice-by-slice imaging found in conventional CT. The images are then reconstructed in a visualizable 3D data set using a variation of the algorithm developed by Feldkamp et al in 1994. CBCT offers numerous advantages compared to traditional 2D radiography, including a lack of superimposition, 1:1 measurements, the absence of geometric distortions, and 3D display. It is important to note that by utilizing a relatively low ionizing radiation, CBCT offers 3D representation of hard tissues with minimal soft tissue information.

Conventional CT systems offer similar advantages (in addition to providing information about soft tissue); however, image acquisition requires much higher levels of ionizing radiation and a longer scanning time. In addition, the larger size of conventional CT units makes them poor alternatives for dental offices.

This article presents a literature review related to clinical applications of CBCT in dental practice.

Materials and methods

Using the phrase “cone beam computerized tomography in dentistry,” a literature search was conducted via PubMed for articles published between January 1, 1998 and June 15, 2010. The search revealed a total of 540 articles. A detailed screening revealed 411 articles focused on physical properties and manufacturing specifications. These articles were excluded, leaving 129 articles to be categorized according to discipline and application. A category was chosen arbitrarily for...
articles that could have been classified in more than one discipline; however, care was exerted to ensure consistency in categorization of duplicate applications.

Results
Of the 129 CBCT-related articles, 34 (26.3%) related to oral and maxillofacial surgery, 33 (25.6%) to endodontics, 21 (16.3%) to implant dentistry, 15 (11.6%) to orthodontics, 12 (9.3%) to general dentistry, 7 (5.4%) to temporomandibular joints (TMJs), 6 (4.65%) to periodontics, and 1 (0.8%) to forensic dentistry (Chart 1).

Applications in oral and maxillofacial surgery
3D images acquired with CBCT have been used to investigate the exact location and extent of jaw pathologies and assess impacted (Fig. 1) or supernumerary teeth and the relationship of these teeth to vital structures.6-23 CBCT images are used for pre- and postsurgical assessment of bone graft recipient sites and to evaluate osteonecrosis changes of the jaws (such as those associated with bisphosphonates) and paranasal sinus pathology and/or defect.10,11,24-28 CBCT technology has also been used for thorough pretreatment evaluations of patients with obstructive sleep apnea, to determine an appropriate surgical approach (when necessary).28,29

As CBCT units become more widely available, dentists have increasingly utilized this technology to evaluate maxillofacial trauma. In addition to overcoming the structural superimpositions that can be seen in panoramic images, CBCT allows accurate measurement of surface distances.30,31 This particular advantage has made CBCT the technique of choice for investigating and managing midfacial and orbital fractures, post-fracture assessment, interoperative visualization of the maxillofacial bones, and intraoperative navigation during procedures involving gunshot wounds.32-37

CBCT is used widely for planning orthognathic and facial orthomorphic surgeries, where detailed visualization of the interocclusal relationship and representation of the dental surfaces to augment the 3D virtual skull model is vital. Utilizing advanced software, CBCT allows for minimum visualization of soft tissue, allowing dentists to control post-treatment esthetics and evaluate the outline of the lip and bony regions of the palate in cases of cleft palate.38-43

Applications in endodontics
CBCT imaging is a useful tool for diagnosing periapical lesions (Fig. 2).2,6,44-54 While controversial, several studies have suggested that contrast-enhanced CBCT images can be used to differentiate between apical granulomas and apical cysts
by measuring the lesion’s density (Fig. 3 and 4). Others have described the use of CBCT as a tool to categorize the origin of the lesion as endodontic or non-endodontic, which might suggest an alternate course of treatment. The validity of these topics is currently under debate; however, they do underline the need for (as well as the popularity of) non-invasive techniques to diagnose lesions that traditionally had been diagnosed through invasive procedures.

Several clinical case reports have focused on using high-resolution CBCT images to detect vertical root fractures. CBCT is considered to be superior to periapical radiographs for detecting vertical root fractures, measuring the depth of dentin fracture, and detecting horizontal root fractures.

CBCT imaging also allows for early detection of inflammatory root resorption, a diagnosis that is rarely possible when using conventional 2D radiographs.

Not only can CBCT detect root resorption (external or internal) and cervical resorption, it can also identify the extent of a lesion. CBCT can be used to determine the number and morphology of roots and associated canals (both main and accessory), establish working lengths, and determine the type and degree of root angulation. CBCT offers a far more accurate evaluation of existing root canal obturations than 2D imaging. CBCT is also used to detect pulpal extensions in talon cusps and the position and location of fractured instruments. Because of its reliability and accuracy, CBCT has also been used to evaluate canal preparation with different instrumentation techniques.

CBCT is a reliable presurgical tool for assessing a tooth’s proximity to adjacent vital structures, allowing for accurate measurement of the size and extent of a lesion and the anatomy of the area. In post-trauma emergency cases where tooth assessment is required, CBCT imaging can help dentists to determine the most suitable treatment approach.
Applications in implant dentistry
The increasing need for dental implants to replace missing teeth requires a technique capable of obtaining highly accurate alveolar and implant site measurements to assist with treatment planning and avoid damage to adjacent vital structures during surgery. In the past, such measurements generally were obtained by utilizing 2D radiographs and (in specific cases) with the aid of conventional CT. However, CBCT is the preferred option for implant dentistry, providing greater accuracy in measuring compared to 2D imaging, while utilizing lower doses of radiation (Fig. 5 and 6). New software has reduced the possibility of malpositioned fixtures and damaged anatomical structures. CBCT has reduced implant failures by providing information about bone density, the shape of the alveolus, and the height and width of the proposed implant site for each patient.

CBCT does not provide accurate Hounsfield unit (HU) numbers; as a result, bone density numbers measured with this technique cannot be generalized over a group of CBCT units or patients. However, CBCT’s effectiveness in quantifying and assessing the shape of the alveolus has led to improved case selection. By knowing in advance the complications that can occur during a specific proposed treatment, the treatment plan can be designed to address the complications or to plan an alternate treatment. CBCT is commonly utilized in postsurgical evaluations to assess bone grafts and the implant’s position in the alveolus (Fig. 7–10).

Applications in orthodontics
The introduction of new software in orthodontic assessment, such as Dolphin (Dolphin Imaging & Management Solutions) and InVivo Dental (Anatomage), has allowed dentists to use CBCT images for cephalometric analysis, making it the tool of choice for assessing facial growth, age, airway function, and disturbances in tooth eruption. CBCT is a reliable tool for assessing the proximity of impacted teeth to vital structures that could interfere with its orthodontic movement. When mini-implants are required as temporary anchors, CBCT offers visual guides for safe insertion, thus avoiding accidental and irreparable damage to the existing roots.

Assessing bone density before, during, and after treatment can show whether it is decreasing or remaining the same (Fig. 11).
CBCT displays multiple views of the maxillofacial complex with a single scan, giving dentists access to anterior, coronal, and axial images, in addition to a 3D reconstruction of the bony skeleton. These images can be rotated, allowing dentists to visualize multiple planes and angles, including some that are not available with 2D radiography.108,109 CBCT images are self-corrected for magnification, producing orthogonal images with a practical 1:1 measuring ratio; as a result, CBCT is considered a more accurate option than panoramic and traditional 2D images.110

**Applications in TMJ disorders**

Diagnostic imaging of the TMJ is crucial for proper diagnosis of diseases and dysfunctions associated with joint conditions. According to Tsiklakis et al, although CT is readily available, it is not very popular in dentistry, due in large part to its high cost and the high dose of radiation involved.111 CBCT makes it possible to examine the joint space and the true position of the condyle within the fossa, which is instrumental in revealing possible dislocation of the joint disk.2,111 CBCT’s accuracy and lack of superimposition makes it possible to measure the roof of the glenoid fossa and visualize the location of the soft tissue around the TMJ, which can offer a workable diagnosis and reduce the need for MRI.112-114 According to Tsiklakis et al, MRI “is considered one of the most useful investigations since it provides images of both soft tissue and bony components.”111 While MRI is recommended for TMJ soft tissue evaluation, CBCT offers lower doses of radiation. However, it should be emphasized that unlike CT and MRI, CBCT does not provide soft tissue detail.

These advantages outlined above have made CBCT the best imaging device for cases involving trauma, fibro-osseous ankylosis, pain, dysfunction, and condylar cortical erosion and cysts.2,6,86,115-117

**Applications in periodontics**

According to Vandenberghe et al, 2D intraoral radiography is the most common imaging modality used for diagnosing bone morphology, such as periodontal bone defects. However, the limitations of 2D radiography could cause dentists to underestimate the amount of bone loss or available bone due to projection errors and has led to errors in identifying reliable anatomical reference points.118 These findings confirm the observation by Misch et al that 2D radiographs are inadequate for detecting changes in bone level or determining the architecture of osseous defects.119 CBCT provides accurate measurement of intrabony defects and allows clinicians to assess dehiscence, fenestration defects, and periodontal cysts.2,120-122 While CBCT and 2D radiographs are comparable in terms of revealing interproximal defects, only 3D imaging such as CBCT can visualize buccal and lingual defects.2,6,118,119,123

CBCT has been used to obtain detailed morphologic descriptions of bone as accurately as direct measurement with a periodontal probe.2,118,119 CBCT can also be used to assess furcation involvement of periodontal defects and allow clinicians to evaluate postsurgical results of regenerative periodontal therapy.2,6,123

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**Table 1. Typical doses (in MsV) produced by dental radiological procedures.11**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoral (F speed, rectangular collimator)</td>
<td>0.001</td>
</tr>
<tr>
<td>Intraoral (E speed, round collimator)</td>
<td>0.004</td>
</tr>
<tr>
<td>Full-mouth set (E speed, round collimator)</td>
<td>0.080</td>
</tr>
<tr>
<td>Lateral cephalometric (F speed, rare-earth screen)</td>
<td>0.002</td>
</tr>
<tr>
<td>Dental panoramic technique (F speed, rare-earth screen)</td>
<td>0.015</td>
</tr>
<tr>
<td>Cone beam CT, both jaws</td>
<td>0.068</td>
</tr>
<tr>
<td>Hospital CT, both jaws</td>
<td>0.600</td>
</tr>
</tbody>
</table>

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Applications in operative dentistry
Based on the literature, CBCT cannot be justified for detecting occlusal caries. Not only does CBCT deliver higher doses of radiation than conventional 2D radiographs, it provides lower resolution than intraoral radiographs.6 Table 1 summarizes typical radiation doses from various dental radiological procedures.6

Applications in forensic dentistry
Age estimation is an important aspect of forensic dentistry. It is imperative that clinicians are able to estimate the age of the individuals placed in the legal system (and those who are deceased) as accurately as possible. This is particularly the case in Europe, as Yang et al noted in 2006: “Every year thousands of unaccompanied minors with no official identification documents trespass the borders of all European countries hoping to find shelter and protection in the country of destination. On top of that, a lot of criminal acts are committed by individuals pretending to be beneath the age of majority. In all these cases, verification of chronological age is required in order to be entitled to a guardian and social benefits, as is the case in Belgium unaccompanied minors.”124 The literature is populated with articles for estimating age based on the correlation of changes of teeth related to age. Enamel is largely immune from such changes beyond normal wear and tear; however, the pulpodentinal complex (dentin, cementum, and the dental pulp) shows physiologic and pathological changes with advancing age.124

Typically, extraction and sectioning are required to quantify these morphological changes, which is not always a viable option. CBCT, however, provides a non-invasive alternative.124

Discussion
CBCT scanners represent a significant advancement in dental and maxillofacial imaging since their introduction to dentistry in the late 1990s.125 This literature review revealed that of the 540 articles on CBCT published in the last 12 years, 129 demonstrated clinical applications; most of these 129 articles related to oral and maxillofacial surgery, endodontics, implants, and orthodontics. CBCT use in operative dentistry is limited because of its higher radiation dose compared to conventional 2D radiography and its inability to provide new or additional diagnostic information. Also, more research is required to explore the various benefits of CBCT in the field of forensic dentistry.

Although this review did not discover any articles concerning prosthodontic applications of the 3D scanner, the improved standard of care seen in prosthodontic treatment can be attributed to CBCT use related to other dental specialties. For example, CBCT has been used for prosthetic-driven implant placement, maxillofacial prosthodontics, and TMD evaluations, which in turn have increased the success of prosthodontic treatment by incorporating additional patient data into the treatment plan. CBCT images are an important adjunct in complex treatment cases, particularly in cases where multiple teeth and bony areas must be assessed (Fig. 12–15).

The newer CBCT systems can be used for specific dental applications; in addition, they offer higher resolution and lower exposure and are less expensive than previously available systems.
Table 2. Basic principles concerning the use of CBCT in dental applications.126

- CBCT examinations must not be carried out unless a history and clinical examination have been performed.
- CBCT examinations must be justified for each patient to demonstrate that the benefits outweigh the risks.
- CBCT examinations should potentially add new information to aid the patient’s management.
- CBCT should not be repeated routinely on a patient without a new risk/benefit assessment having been performed.
- When accepting referrals from other dentists for CBCT examinations, the referring dentist must supply sufficient clinical information (results of a history and examination) to allow the CBCT practitioner to perform the justification process.
- CBCT should be used only when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiography.
- CBCT images must undergo a thorough clinical evaluation (radiological report) of the entire image dataset.
- Where it is likely that evaluation of soft tissues will be required as part of the patient’s radiological assessment, the appropriate imaging should be conventional medical CT or MRI, rather than CBCT.
- CBCT equipment should offer a choice of volume sizes, and examinations must use the smallest volume that is compatible with the clinical situation if this provides a lower radiation dose to the patient.
- Where CBCT equipment offers a choice of resolution, the resolution compatible with adequate diagnosis and the lowest achievable radiation dose should be used.
- A quality assurance program must be established and implemented for each CBCT facility, including equipment, techniques, and quality control procedures.
- Aids to ensure accurate positioning (light beam markers) must always be used.
- All new installations of CBCT equipment should undergo a critical examination and detailed acceptance tests before use to ensure optimal radiation protection for staff, patients, and members of the public.
- CBCT equipment should undergo regular routine tests to ensure that radiation protection, for both practice/facility users and patients, has not deteriorated significantly.
- For staff protection from CBCT equipment, the guidelines detailed in Section 6 of the European Commission document Radiation protection 136. European guidelines on radiation protection in dental radiology should be followed.
- All those involved with CBCT must have received adequate theoretical and practical training for the purpose of radiological practices and relevant competence in radiation protection.
- Continuing education and training after qualification are required, particularly when new CBCT equipment or techniques are adopted.
- Dentists responsible for CBCT facilities who have not previously received "adequate theoretical and practical training" should undergo a period of additional theoretical and practical training that has been validated by an academic institution (university or equivalent); where national specialist qualifications in dentomaxillofacial radiology exist, the design and delivery of CBCT training programs should involve a dentomaxillofacial radiologist.
- For dentoalveolar CBCT images of the teeth, their supporting structures, the mandible, and the maxilla up to the floor of the nose (for example, 8 cm X 8 cm or smaller fields of view), the clinical evaluation (radiological report) should be made by a specially trained dentomaxillofacial radiologist or, when this is not possible, an adequately trained general dental practitioner.
- For non-dentoalveolar small fields of view (for example, temporal bone) and all craniofacial CBCT images (fields of view extending beyond the teeth, their supporting structures, the mandible [including the TMJ], and the maxilla up to the floor of the nose), the clinical evaluation (radiological report) should be made by a specially trained dentomaxillofacial radiologist or a clinical (medical) radiologist.

While CBCT offers numerous advantages over 2D radiography, there are inherent limitations requiring precise attention to selection criteria and indications. For example, CBCT is susceptible to motion artifacts (including artifacts unique to CT technology) and beam hardening around dense objects; in addition, CBCT has low contrast resolution and a limited ability to visualize internal soft tissues. Many new CBCT units contain flat-panel detectors that are less prone to beam hardening artifacts, so they are able to provide more detailed information. However, due to lack of consistency between manufacturers, CBCT cannot generate accurate HU measurements and is therefore unreliable for quantifying bone density.4

In the authors’ opinion, it is crucial to respect the as low as reasonably achievable (ALARA) radiation dose concept. This tenet should not be misconstrued as a reason to avoid using CBCT units with higher doses that will provide the necessary information. There are no strict protocols regarding when the technology is to be used; rather, individual dentists, oral radiologists, and neuro-radiologists must actively monitor their practice's protocols. Interpreting these images requires extensive anatomical knowledge of areas that have traditionally been in the realm of dentistry and neuro-radiology.4 Possessing the knowledge...
and experience to interpret the scanned data accurately is necessary to determine why the imaging was required and to interpret the incidental findings that appear in the scan but are beyond the traditional scope of dentistry, such as abnormalities that can be detected in any neighboring region. Dentists must determine on a case-by-case basis if CBCT increases diagnostic knowledge and improves the patient’s standard of dental care. Such evaluation requires continuous training and education on the part of dentists and researchers.

The increasing popularity of CBCT has led to a large number of units with minor (but sometimes important) variations, which in turn has led to uncontrolled and non-evidence-based reporting of radiation values. This unconfirmed reporting can be attributed to the limited technical knowledge of medical imaging devices among new units; in response, the European Academy of Dental and Maxillofacial Radiology has developed basic principles for the use of CBCT in dental applications (Table 2).126

Summary
Based on the literature, the majority of CBCT applications in dental practice relate to the specialties of oral and maxillofacial surgery, endodontics, implants, and orthodontics. CBCT examinations must not be performed unless they are necessary and the benefits clearly outweigh the risks. When utilizing CBCT, the entire image dataset (that is, a radiological report generated by an oral surgeon, neurologist, or general radiologist familiar with the head and neck region) must be evaluated thoroughly to maximize the clinical data obtained and ensure that medically serious incidental findings are reported.

Additional research should focus on obtaining accurate data regarding the radiation doses of CBCT systems, as these systems have a small detector size and limited field of view and scanned volume. CBCT systems with larger fields of view with higher resolution and fewer metallic artifacts for orthodontic and orthognathic surgery are not yet available. Additional investigation is necessary to better determine CBCT applications in forensic dentistry and prosthetics.

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References:
Information Technology/Computers

Applications of CBCT in dental practice

52. Hassan B, Metska ME, Ozoek AR, van der Stelt P, Wesselink PR. Comparison of five cone beam computed tomography systems for the detection


Manufacturers
Anatomage, San Jose, CA
Whitaker Imaging & Management Solutions, Chatsworth, CA
NewTom, Vicenza, Italy
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