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**Ministry of higher education and scientific research**

**University of Baghdad**

**College of Dentistry**

**Cone Beam Computed Tomography and its Application in Orthodontics**

**A project submitted to the College of Dentistry in Baghdad University for partial fulfillment of the requirement of B.D.S**

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**2016-2017**

**Acknowledgement:**

I would like to thank my supervisor Dr. Abeer Basim Mahmood for her valuable advice, guidance and encouragement throughout this work.

Also my special thanks to my family for their encouragement and support.

## Abstract

The application of innovative technologies in dentistry and orthodontics has been very interesting to observe. The development of cone-beam computed tomography (CBCT) as a preferred imaging procedure for comprehensive orthodontic treatment is of particular interest. The information obtained from CBCT imaging provides several substantial advantages. For example, CBCT imaging provides accurate measurements, improves localization of impacted teeth, provides visualization of airway abnormalities, it identifies and quantifies asymmetry, it can be used to assess periodontal structures, to identify endodontic problems, to plan placement sites for temporary skeletal anchorage devices, and to view condylar positions and temporomandibular joint (TMJ) bony structures according to the practitioner’s knowledge at the time of orthodontic diagnosis. Moreover, CBCT imaging involves only a minimal increase in radiation dose relative to combined diagnostic modern digital panoramic and cephalometric imaging. The aim of this article is to provide a comprehensive overview of CBCT imaging, including its technique, advantages, and applications in orthodontics.

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**1.1 Introduction:**

Cone Beam CT is a medical imaging modality, which has been applied in different fields of medicine (*e.g.* cardiac imaging, radiotherapy). Recently, this technique has been applied to dental imaging. [1]

Craniofacial CBCT was designed to offset some of the limitations of conventional CT scanning devices [2] while also reducing the exposure of patients to radiation. A CBCT scan with a single revolution of the radiation source is sufficient to scan the entire maxillofacial region [3]. CBCT technology is based on the use of a cone-shaped X-ray beam that is directed through the patient and the remnant beam is captured on a flat two-dimensional (2D) detector [4]. The X-ray source and detector are able to revolve about a patient’s head, and a sequence of two-dimensional (2D) images is generated. These 2D images are then converted into a 3D image using computer software. The rapid movement of the X-ray tube and digital detector through 180°, or more frequently through 360°, produces essentially instantaneous and precise 2D and 3D radiographic images of an anatomical structure. Furthermore, these images are only restricted by the system’s distinctive, or designated, field-of-view (FOV).

**1.2 Cone beam computed tomography in orthodontics:**

We have currently been through modern times in Orthodontics. In a retrospective view of our science and art, we envisage a Classical era from the end of the XIX century until the 60s with the legacy of Edward Hartley Angle and his eminent pupils, including Charles Tweed, Broadbent and Brodie.[5][6] After the Classical era, a Contemporary era started in the 70s not only with the development of specific occlusal objectives and the Straight-Wire appliance by Andrews, but also with the development of orthognatic surgery and facial analysis for orthodontic diagnosis.[7][8] When we look to the present, we see our time being highlighted by two major vanguard advents: tridimensional images and skeletal anchorage.

Cone-beam computed tomography (CBCT) together with digital dental models and 3D facial photographs personify the modernity of the present. Introduced in 1998, [9] CBCT is in its adolescence, but has contributed with over seven hundred international publications in Orthodontics, according to a search at Pub med database. Evidence related to CBCT has provided important development in three levels: orthodontic diagnosis; orthodontic or orthodontic-surgical treatment planning; and knowledge of treatment outcomes. It is not difficult to fall in love for CBCT scans, once they allow three-dimensional visualization of the morphology of the face and cranium, and demonstrate one's anatomy in multiplanar sections with adequate resolution and sharpness. [10] CBCT presents high accuracy and precision, sensibility and specificity, as well as absence of image amplification. [11-24] Faced with these advantages, the following question recurrently arises: Can CBCT be indicated as a routine in Orthodontics?

As every light has its shadows, a method does not have advantages, only. CBCT has the drawback of having a higher radiation dose compared to conventional radiograph frequently requested in Orthodontics.[25][26] Effective radiation dose is the sum of the dose received by all irradiated tissues and organs, considering both tissue weight and the quality of ionizing radiation in terms of biological effects.[27] Effective radiation dose represents a stochastic risk to health, in other words, the probability of carcinogenesis and genetic effects on irradiated tissues.[27] During X-ray examination, millions of photons pass through patient's cells and can cause damage to DNA molecules due to ionization.[27] The majority of changes caused to genetic material is reversible and immediately repaired.[27] However, DNA may be rarely, yet permanently altered, thereby establishing a genetic mutation.[27] Fortunately, effective dose and risks related to dental radiation are very small compared to the natural risks of carcinogenesis.[27][28] Nevertheless, some limited evidence on the increase of radiation-related tumor in the brain and thyroid glands requires caution and rationality before indicating X-ray examination in Dentistry, including conventional radiographs.[27] This concern is amplified in children, as they present tissues with higher radio sensitivity, greater number of cell divisions and a longer lifetime spam for carcinogenesis development.[28]

The effective radiation dose of CBCT depends on the scanner, the field of view (FOV) and on the acquisition protocol, particularly considering resolution or voxel dimension.[25] For a detailed analysis of CBCT effective dose, we recommend consulting Table 3 of the manuscript issued by the American Academy of Oral and Maxillofacial Radiology, published in 2013 with the goal of discussing CBCT recommendations in Orthodontics.[25] The aforementioned table also compares the effective radiation dose of extra oral radiographs and multi-slice computed tomography. These data are summarized in Table 1.

**Table 1** Effective radiation dose (EICRP 2007) expressed in microSieverts (mSv) and produced by cone-beam computed tomography at different resolutions and fields of view (FOV) in comparison with multi-slice CT and conventional radiograph. Data adapted from the American Academy of Oral and Maxillofacial Radiology (2013). [25] Great variation in radiation dose according to each type of scan occurs due to differences caused by the scanner and the acquisition protocol.

| EXAMINATION | Effective dose (mSv) |
| --- | --- |
| CBCT of face and cranium (FOV > 15 cm) | 52 to 1073 |
| CBCT of face (FOV 10 - 15 cm) | 61 to 603 |
| CBCT of the jaws (FOV < 10 cm) | 18 to 333 |
| Multi-slice CT | 426 to 1160 |
| Panoramic radiograph | 6 to 50 |
| Cephalogram | 2 to 10 |

**Table 2** Basic principles to be followed in daily clinical practice before requesting cone-beam computed tomography

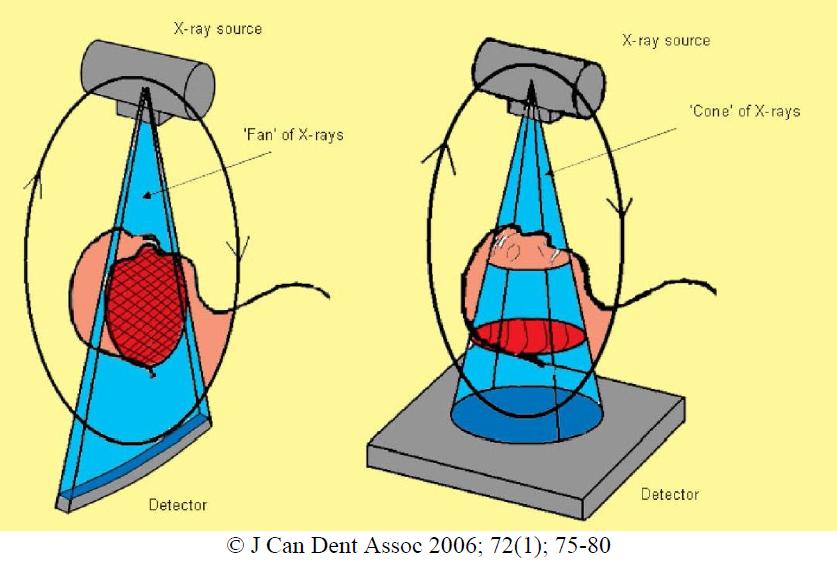
|  |  |
| --- | --- |
| Principle 1 | CBCT should not be used routinely for all patients. |
| Principle 2 | CBCT examinations must not be carried out unless  a history and clinical examination have been performed. |
| Principle 3 | CBCT examinations must be justified for each patient. |
| Principle 4 | CBCT field of view (FOV) should be restricted as much as possible. |
| Principle 5 | The lowest achievable resolution should be used  without jeopardizing evaluation of the area of interest. |

|  |
| --- |
| **Localization of impacted teeth and identification of associated root resorption\*** » CBCT should only be used when Multi-slice CT is necessary, in which case CBCT is preferred due to lower radiation dose; or » CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiograph;  **Cleft lip/palate\*** » CBCT should only be used when Helicoidal CT is necessary, in which case CBCT is preferred due to lower radiation dose;  **Mini-implants:** Proper mini-implant placement site\* » CBCT are rarely necessary, except for cases with critical space left for mini-implant placement;  **Severe cases of skeletal discrepancies** » CBCT of the face might be used to develop orthosurgical treatment planning; » Preference is given to patients older than 16 years of age;  **Pre-surgical assessment of impacted teeth** » CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiography;  **Orthognathic surgery planning** » CBCT of the face might be used to develop orthosurgical treatment planning;  **TMJ assessment** » CBCT should only be used when Helicoidal CT is necessary, in which case CBCT is preferred due to lower radiation dose; |

**Table 3** CBCT recommendations for orthodontic purposes, according to the American Academy of Oral and Maxillofacial Radiology (AAOMR). [25]

**1.3 Technical Description of CBCT**

The principle behind this technique, as its name implies, is a cone-shaped X-ray bundle, with the X-ray source and detector (Image Intensifier or Flat Panel Detector) rotating around a point (or field) of interest of the patient (Fig. 1). The conical shape of the beam distinguishes this technique from helical CT, which used a fan-shaped beam. As a result of the acquisition of two-dimensional projections throughout this rotation, only one rotation or less is needed to acquire a full (three-dimensional) dataset.



Fig, (1)

The images received by the detector are then compiled by the computer into volumetric data (primary reconstruction). This can then be visualized as two-dimensional multi-planar reformatted slices or in three dimensions by using surface reconstruction or volume rendering.

The cone-shaped beam used in CBCT is produced in a vacuum tube called an X-ray tube. There are different parameters characterizing the X-ray beam. The beam quality is defined by the X-ray spectrum, the shape of which is defined by the voltage peak (kVp) over the tube, the anode material and the filtration of the produced X-ray beam. The quantity of X-rays is linearly related to the anode current (mA) and exposure time (s). Furthermore, the collimation defines the width and height of the primary beam and therefore the size of the reconstructed field of view (FOV).

By rotating the beam around a fixed point (isocentre) in the object of interest and acquiring projections from many different angles, a (typically cylindrical) three-dimensional volume can be reconstructed. Typically, a few hundreds of projections are collected. Although a 360° rotation is used in general, some devices have implemented a 180° or slightly greater rotation arc, which suffices for image reconstruction and leads to significant radiation reduction. The two-dimensional attenuation profiles obtained from all angles are then reconstructed into a three-dimensional matrix, containing volume elements (voxels) each having a certain grey value which represents the average density within this volume element. The grey value for each voxel is determined by the reconstruction algorithm, by combining the information from all obtained projections.

There are generally two types of algorithms used in clinical practice. The most commonly used algorithm is the modified Feldkamp algorithm, which uses filtered back projection. Recently, iterative reconstruction methods have gained attention as an alternative reconstruction method. Using iterative reconstruction, the acquisition process is modeled and consecutive cycles of reconstruction and reprojection are performed. After an initial reconstruction, projections of the reconstructed volume are simulated and compared with the actual raw data (i.e. the acquired projections). The reconstruction is then repeated and altered based on the difference between actual and simulated projections. This process is repeated for a number of iterations. A great benefit for this technique is that every part of the acquisition process can be modeled, which indicates its great potential in artifact reduction. However, iterative reconstruction requires a great amount of computing power, and it is generally expected to be implemented into practice more and more with the continuing increase of processing speed in workstations.

In conclusion, after a gradual introduction of this modality into dental radiology, the use of CBCT has steadily increased, and the market has been growing with a wide range of CBCT devices. These devices, although based on the same principle, exhibit great differences regarding exposure parameters and other quality factors, requiring an objective analysis of the performance of these devices, and an optimized implementation into dental practice. [1]

**1.4 Advantages of CBCT**

Being considerably smaller, CBCT equipment has a greatly reduced physical footprint and is approximately one quarter to one fifth the cost of conventional CT. CBCT provides images of highly contrasting structures and is therefore particularly well suited for the imaging of osseous structures of the craniofacial area. The use of CBCT technology in clinical dental practice provides a number of advantages for maxillofacial imaging. [29]

**1) Rapid scan time:**

Because CBCT acquires all projection images in a single rotation, scan time is comparable to panoramic radiography, which is desirable because artifact due to subject movement is reduced. Computer time for data set reconstruction, however, is substantially longer; it varies, depending on FOV, number of basis images acquired, resolution, and reconstruction algorithm, and may range from approximately 1 minute to 20 minutes.

**2) Beam limitation:**

Collimation of the CBCT primary x-ray beam enables limitation of the x-radiation to the area of interest. Therefore, an optimum FOV can be selected for each patient based on suspected disease presentation and region of interest. Although not available on all CBCT systems, this function is highly desirable because it provides dose savings by limiting the irradiated field to fit the FOV.

**3) Image accuracy:**

CBCT imaging produces images with sub millimeter isotropic voxel resolution ranging from 0.4 mm to as low as 0.076 mm. Because of this characteristic, subsequent secondary (axial, coronal, and sagittal) and multiplanar reformation (MPR) images achieve a level of spatial resolution accurate enough for measurement in maxillofacial applications where precision in all dimensions is important, such as implant site assessment and orthodontic analysis.

**4) Reduced patient radiation dose:**

Published reports indicate that the effective dose [30] varies for various full FOV CBCT devices, ranging from 29 to 477 mSv, depending on the type and model of CBCT equipment and FOV selected [31-33]. Comparing these doses with multiples of a single panoramic dose or background equivalent radiation dose, CBCT provides an equivalent patient radiation dose of 5 to 74 times that of a single film-based panoramic x ray, or 3 to 48 days of background radiation. Patient positioning modifications (tilting the chin) and use of additional personal protection (thyroid collar) can substantially reduce the dose by up to 40% [30, 31]. Comparison with patient dose reported for maxillofacial imaging by conventional CT (approximately 2000 mSv) indicates that CBCT provides substantial dose reductions of between 98.5% and 76.2% [32-34].

**5) Interactive display modes applicable to maxillofacial imaging:**

Perhaps the most important advantage of CBCT is that it provides unique images demonstrating features in 3D that intraoral, panoramic, and cephalometric images cannot. CBCT units reconstruct the projection data to provide interrelational images in three orthogonal planes (axial, sagittal, and coronal). In addition, because reconstruction of CBCT data is performed natively using a personal computer, data can be reoriented so that the patient’s anatomic features are realigned. Basic enhancements include zoom or magnification, window/level, and the ability to add annotation. Cursor-driven measurement algorithms provide the clinician with an interactive capability for real-time dimensional assessment. Onscreen measurements provide dimensions free from distortion and magnification.

**6) Multiplanar reformation**

Because of the isotropic nature of the volumetric data sets, they can be sectioned nonorthogonally. Most software provides for various nonaxial 2Dimages, referred to as MPR. Such MPR modes include oblique, curved planar reformation (providing ‘‘simulated’’ distortion-free panoramic images), and serial transplanar reformation (providing cross-sections), all of which can be used to highlight specific anatomic regions and diagnostic tasks (Fig. 2), which is important, given the complex structure of the maxillofacial region. Because of the large number of component orthogonal images in each plane and the difficulty in relating adjacent structures, two methods have been developed to visualize adjacent voxels.



Fig. 2 Curved MPR simulated ‘‘panoramic’’ image from CBCT showing CBCT applications in

Temporomandibular joint assessment. Reformatted ‘‘panoramic’’ image (top) showing right side

Condyle differences in shape compared with normal left. Cropped paracoronal reformatted

images clearly showing subcortical cystic defects in surface of right condyle as compared

with the left, indicative of active degenerative joint disease. Images generated using i-CAT

(Imaging Sciences International, Hatsfield, Pennsylvania).

**1.5 Limitations of CBCT**

**1) Limited contrast resolution:**

One major disadvantage of CBCT is that it can only demonstrate limited contrast resolution, mainly due to relatively high scatter radiation during image acquisition and inherent flat panel detector related artifacts.[35][36] If the objective of the examina­tion is hard tissue only, using a CBCT would not be a problem; however, CBCT is not sufficient for soft tissue evaluation. [37]

**2) Risks of radiation dose:**

Risks have also been noted in the radiation dose needed with CBCT although it is generally believed that the radiation dose of CBCT is signifi­cantly lower than a conventional CT. [38] The effective radiation dose of CBCT can be affected to an order of magnitude by the factors of patient size, FOV, region of interest, and resolution. A careful selec­tion of all these parameters is needed to optimize diagnostic information and reduce the patient’s ex­posure. [39] According to 2009 ICRP reports, the risk of adult patient fatal malignancy related to CBCT is between 1/100,000 and 1/350,000, and when using the technology for children, the risk could be twice as much.[40][41][39] Potential benefits of using CBCT in dentistry for assessment and diagnosis of pathologies and presurgical planning are undisputed. However, due to the additional radiation exposure necessary to achieve the desired results, justification of CBCT must be substantiated.

**3) Streaking and motion artifacts:**

Streaking and motion artifacts are largely lim­ited with current CBCT units; however, they are not completely avoided. Manufacturers have developed their own specific filters to resolve these problems, [42] but it is unclear whether the reconstruction of im­ages will reduce the image quality or quantity. More studies are needed in this area to provide a definitive answer.

**1.6 THE CONTROVERSY**

In November, 2010, a publication in "The New York Times" reported the abuse of dental professionals in indicating CBCT to children and adolescents[43]

The article had great impact in the United States and encouraged the American Association of Orthodontics and the American Academy of Oral and Maxillofacial Radiology to prepare guidelines for CBCT use in orthodontics [25]during the 3-year interval between these two publications, much controversy was seen on this subject.

In 2011, 83% of postgraduate programs in Orthodontics in the US and Canada reported to use CBCT. The majority (82%) of them recommended CBCT only in selected cases, including impacted teeth (100% of programs), craniofacial anomalies (100% of programs) and TMJ (67%) or upper airway assessment (28%). Only 18% of programs reported replacing conventional radiograph by CBCT. Most of them, however, routinely used conventional radiograph for control during orthodontic treatment.

CBCT recommendation in Orthodontics raised so much controversy that the American Journal of Orthodontics and Dentofacial Orthopedics published a Point-Counterpoint session on the subject in 2012. On one side, in defense of routine use of CBCT for comprehensive orthodontic treatment, was Dr. Brent Larson, director of the Orthodontic division of the University of Minnesota, United States [45]

On the other side, against the idea of routine use of CBCT for comprehensive orthodontic treatment, was Dr. Demetrius Halazonetis from the University Of Athens, Greece [46]. The aforementioned publication also portraits the dichotomy between United States and Europe concerning the conservative approach of CBCT use.

Defense was based on arguments such as increased geometrical accuracy and reliability of measurements on CBCT images; high sensitivity for localization of impacted teeth and identification of related root resorption; easiness in quantifying discrepancies in cases of facial asymmetry; sharp visualization of TMJ, upper airway and tooth buccal and lingual bone plates; significant frequency (10%) of incidental findings; ease in mini-implant and customized fixed appliance planning; confidence provided by CBCT to therapeutic choices; the possibility to simulate and demonstrate the therapy of choice to patients; and last but not least, the evidence that CBCT radiation dose is minimal in comparison to the sum of radiation doses of panoramic radiograph, cephalometric radiograph and the full set of periapical radiographs [45].

**1.7 Orthodontic applications of CBCT**

In general, orthodontics has relied on 2D X-rays to assess 3D structures. However, CBCT provides a 3D visualization of the craniofacial skeleton, and this has applications in various orthodontic situations (see table 4).

**Table 4** Application of CBCT in orthodontics.

| **Orthodontic situation** | **CBCT application** |
| --- | --- |
| Diagnosis | Assessment of skeletal structures and dental structures |
| • Skeletal jaw relation |
| • Symmetry/asymmetry |
| 3D evaluation of impacted tooth position and anatomy |
| Growth assessment |
| Pharyngeal airway analysis |
| Assessment of the TMJ complex in three dimensions |
| Cleft palate assessment |
|  | |
| Treatment planning | Orthognathic surgery treatment planning in true 1:1 imaging |
| Planning for placement of temporary anchorage devices (TADs) |
| Accurate estimation to space requirement for unerupted/ impacted teeth |
| Used in association with CAD/ CAM technology for construction of custom appliances. (Lingual orthodontic appliance) |
|  | |
| Treatment progress | Assessment of dentofacial orthopedics |
| Outcomes of alveolar bone grafts in cleft palate cases |
| Orthognathic Surgery superimposition |
|  | |
| Risk assessment | Investigation of orthodontic-associated paraesthesia |
| Assessment of orthodontics induced root resorption |
| Post treatment TMD |

\*(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.1 Application in orthodontic diagnosis:**

**1.7.1.1 Assessment of skeletal and dental structures**

Conventional cephalometric radiography is limited in its application by the expression of 3D structures onto a 2D plane. As a result, the superimposition of anatomical structures interferes with landmark identification and can lead to magnification and distortion of the image obtained. In contrast, CBCT imaging in association with computer software allows anatomical structures to be properly represented in all three viewing planes – sagittal, coronal, and transverse.

Landmark identification is also greatly enhanced in CBCT images with magnification and adjustments in contrast. In 2008, Van Vlijmen et al. [47] stated that the reproducibility of measurements on cephalometric radiographs obtained from CBCT scans was better than that achieved with conventional cephalograms. Multiplanar views are especially advantageous in identifying bilateral landmarks such as condylion, gonion, and orbitale, which are frequently superimposed in conventional radiographs [48]. However, CBCT imaging need not replace conventional radiography, although additional conventional imaging is generally not necessary when CBCT scans are acquired for an orthodontic diagnosis

**1.7.1.2 Evaluation of impacted teeth**

CBCT is commonly used to assess an impacted tooth and its position (Fig. 3). Research has shown that enhanced precision in the localization of canine teeth and improved estimations of the space conditions in the arch can be obtained with CBCT, and this can greatly affect diagnosis and treatment planning to facilitate a more clinically-orientated approach. Small volume CBCT is also justified as a supplement to routine panoramic X-rays in the following cases: when canine inclination in the panoramic X-ray exceeds 30°, when root resorption of adjacent teeth is suspected, and/or when the canine apex is not clearly discernible in the panoramic X-ray, implying dilaceration of the canine root [49].

When comparing conventional radiography and CBCT, Katheria et al. [50]found that CBCT provides more information regarding the location of pathology, the presence of root resorption, and treatment planning. However, the benefits of CBCT imaging must be weighed against the radiation risk to pediatric patients and the complexity of the pathology involved.

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Object name is gr2.jpgFig. (3) CBCT image of impacted upper left canine

(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.1.3 Growth assessment**

CBCT scans can be used to reliably assess cervical vertebrae maturity, which provides a consistent evaluation of skeletal maturity [51].

**1.7.1.4 Pharyngeal airway analysis**

Lateral cephalograms have been routinely used to assess the airway using techniques involving both tissue and soft tissue points. Conventional radiography and reconstructed 2D CBCT images provide similar assessments of the airway. In comparison, axial cuts of 3D CBCT scans (Fig. 4) provide soft tissue points that are derived from the projection of shaded areas, which are more clearly visible in axial CBCT cuts compared with conventional radiographs, thereby enhancing airway assessment [52]. Three-dimensional CBCT-assisted airway analysis also facilitates the diagnosis and treatment planning of complex anomalies including enlarged adenoids and obstructive sleep apnea (OSA**)**. In 2007, Ogawa et al. [53] investigated airway morphology in OSA-affected patients. The apnea-affected subjects showed a significant decrease in airway volume, area, and distance, thereby highlighting the importance of CBCT in the diagnosis of this condition.

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Object name is gr3.jpg

Fig. (4) CBCT image for airway analysis

(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.1.5 Assessment of the temporomandibular joint (TMJ) complex in three dimensions**

In 2007, Honeyet al. [54]compared CBCT imaging of the TMJ complex with panoramic radiography and linear tomographic views, and found that the CBCT images (Fig. 5) were more accurate and showed superior reliability in diagnosing condylar morphology disturbances and erosion. For a complete bilateral TMJ exam, an average of four tomographic cuts in both the lateral and frontal planes are needed for each TMJ. In addition, scout images preceding the actual tomography are needed. In comparison, a CBCT examination requires less time, it includes image data for both the right and left TMJs from a single 360° rotation scan around the patient’s head, and it simplifies patient positioning. Additional advantages include a potentially lower radiation dose and the possibility of multiplanar views and image manipulation in the form of rotated views [55]. When validating the use of CBCT for TMJ analysis, the clinician should deliberate whether the information acquired will affect the management of the patient. Findings such as hard tissue erosions, remodeling, or the presence of any structural deformities may be absolutely documentary and may have no bearing on treatment protocol. In general, CBCT is not the imaging of choice for TMJ disorders such as myofacial pain dysfunction or internal disk derangement.

An external file that holds a picture, illustration, etc.
Object name is gr4.jpgFig. (5) CBCT image showing assessment of condylar anatomy.

(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.1.6 Cleft palate assessment**

CBCT for patients with cleft lip and palate (Fig. 6) is useful for both preoperative and therapeutic evaluations. The real-time creation of images in several planes and parasagittal sections through the imaging volume has broad applications in the assessment of cleft palate cases. Three-dimensional reconstructions of images in association with 3D navigation systems allow preoperative evaluations of the cleft palate regarding the volume of the bone defect, the location of the bone defect, the presence of supernumerary teeth, and an appraisal of permanent teeth and alveolar bone morphology [56]. In a study by Albuquerque et al. [57], CBCT was found to be equivalent to multi-slice CT in both the volumetric assessment of bone defects in alveolar and palatal regions and in establishing donor area and the volume of the bone graft to be used in the rehabilitation of cleft patients.

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Object name is gr5.jpg

Fig. (6) CBCT image of a patient with unilateral cleft palate.

(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.2 Applications of CBCT in treatment planning**

**1.7.2.1 Orthognathic surgical planning**

CBCT imaging in tandem with appropriate software and virtual patent-specific models enables the examination of hard and soft craniofacial tissues and their spatial relationships. Virtual anatomical models can be fabricated from CT volumes and co-registered with other available 3D image data. Thus, the virtual models that are generated can be used to recreate or check treatment options, to create anatomically correct substitute grafts, and can be a critical aid during the surgical procedure. In addition, databases may be interfaced with the anatomical models to provide characteristics of the displayed tissues to reproduce tissue reactions to development, treatment, and function.

For example, maxillofacial soft tissues can be ascribed with viscoelastic properties and can be associated with related hard tissues so that replicated manipulation of the hard tissues (e.g., teeth and skeleton) (Fig. 7) produces a correct deformation reaction in the attached soft tissues. This method can offer a more distinct depiction of anticipated changes subsequent to surgical treatment compared with less sophisticated computer modeling [58].

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Object name is gr6.jpg

Fig. (7) Surgical simulation to plan displacement of colored segments

(CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.2.2 Surgical simulation to plan displacement of colored segments**

**(Planning for placement of temporary anchorage devices TADs)**

The placement of TADs can greatly enhance the information derived from CBCT imaging (Fig. 8). Three-dimensional scans are especially useful in evaluating the amount and quality of bone available in the desired site of placement[59]. Therefore, with this single diagnostic imaging method, information about surrounding structures, root proximity, and the morphology of maxillary sinuses and the inferior alveolar nerve canal can be obtained, all of which are important in determining TAD stability and success. Surgical guides that have been developed using a method employing high resolution CBCT scans and rapid prototyping have been shown to provide accurate placement of TADs on the buccal aspect of the jaws [60].Three-dimensional CBCT image-based stereo lithographic surgical stent guides [61]. have also been found to be more accurate than 2D surgical guides in micro implant placement.

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Fig. (8) Planning of TAD placement.

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**1.7.2.3 Accurate estimation of the space requirement for unerupted/impacted teeth**

CBCT scans enable the accurate localization of impacted and/or transposed teeth, and this helps determine the best method for surgical access and bond placement. It also helps delineate the ideal and most efficient path for extrusion into the oral cavity to circumvent or decrease collateral damage. Furthermore, CBCT scans provide the orthodontist with valuable information regarding the teeth neighboring the impacted teeth in terms of root proximity.

This information can then be used to place adjacent teeth and their roots away from the traction path of the impacted tooth so as to avoid untoward changes in these teeth. Another advantage of CBCT over conventional radiographs is its capacity to obtain precise dimensions of an impacted tooth, which aids in estimating and creating the necessary space to accommodate the tooth within the arch.

**1.7.2.4 Fabrication of custom orthodontic appliances**

The fabrication of custom lingual orthodontic appliances has been demonstrated using CBCT image data with existing technology to virtually plan a patient’s treatment and the manufacturing of custom appliances with 3D printing technology [62]**.** Such advances appear to be rapid, and they also promise efficient and effective patient-specific treatments. Correspondingly, Orametrix (Richardson, TX) is a company that has been using CBCT technology for the last several years to provide the data necessary for planning and executing technology-assisted treatment through its SureSmile system [45].

**1.7.3 Application of CBCT in assessing treatment progress and outcome**

**1.7.3.1 Dentofacial orthopedics:**

Cevidanes et al. ;2009[63] previously investigated the possibility of using CBCT scans for evaluating treatment outcomes for Class III growing patients that were treated with maxillary protraction using Class III inter-arch elastics attached to mini-plates. They found that 3D overlays of superimposed models and 3D color coded displacement maps provided visual and quantitative assessments of growth and treatment changes. CBCT scans were able to identify maxillary and mandibular positional changes and bone remodeling relative to the anterior cranial fossa.

Rapid maxillary expansion treatment outcomes have also been evaluated using CBCT images and scans. Overlapping of anatomical structures is able to be circumvented using 3D scans, and hence, skeletal and dental changes can more accurately be evaluated [64].However, there is a need for more research and a definitive analysis regarding the standardization of superimposition areas in 3D scans since the superimposition of 3D surface models is currently a time consuming and operator sensitive process [65].

**1.7.3.2 Orthognathic surgery superimposition**

Studies of surgical treatment outcome may be facilitated by using a new superimposition method (Fig. 9) which enables the operator to superimpose a custom surface mesh of the first CBCT image onto a second CBCT image of the anterior cranial base.An external file that holds a picture, illustration, etc.
Object name is gr8.jpg Fig. (9) Orthognathic superimposition with CBCT imaging. (CBCT imaging – A boon to orthodontics Genevive L. Machado-2014 Oct 22)

**1.7.3.3 Orthognathic superimposition with CBCT imaging**

In 2009, Swennen et al [66]recommended the following three-stage sequence for imaging when evaluating surgical treatment outcomes using CBCT:

1-Stage 1 (3–6 weeks post-operatively): imaging is used to verify the transfer of bony parts. This time frame circumvents post-operative soft tissue swelling which might interfere in occlusion and is prior to bony consolidation, thereby providing proper visualization of osteotomy lines.

2-Stage 2 (6 months to 1 year post-operatively: imaging at this stage evaluates the soft tissue response and should preferably occur after the removal of orthodontic brackets

3-Stage 3 (2 years or more post-operatively): this imaging is used to evaluate long-term changes in surgical treatment.

Almeida et al. (2011) used CBCT volume-derived virtual facial models to evaluate post-surgical changes in the soft tissue overlying the mandible in response to mandibular advancement surgery. They superimposed the virtual models at the cranial base and used color maps to qualitatively evaluate surgical and postsurgical changes. A comparison of color maps derived from CBCT images and corresponding computer software analysis was also reported by Cevidanes et al; 2005 [67]**.**

**References:**

[1] Technical Description of CBCT from University of Manchester. Citing: Scarfe WC, Farman AG, Sukovic P (February 2006). "Clinical applications of cone-beam computed tomography in dental practice". Journal of the Canadian Dental Association. 72 (1): 75–80.

[2] Halazonetis D.J. From 2-dimensional cephalograms to 3-dimensional computed tomography scans. Am. J. Orthod. Dentofacial Orthop. 2005;127:627–637.

[3] Sukovic P., Brooks S., Perez L., Clinthorne N.H. DentoCAT™—a novel design of a cone-beam CT scanner for dentomaxillofacial imaging: introduction and preliminary results. CARS. 2001:700–705.

[4] Scarfe W.C., Farman A.G., Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J. Can. Dent. Assoc. 2006;72(1):75–80.

[5] Wahl N. Orthodontics in 3 millennia. Chapter 3: The professionalization of orthodontics. Am J Orthod Dentofacial Orthop. 2005;127(6):749-53.

[6] Wahl N. Orthodontics in 3 millennia. Chapter 4: The professionalization of orthodontics (concluded). Am J Orthod Dentofacial Orthop. 2005;128(2):252-7.

[7] Wahl N. Orthodontics in 3 millennia. Chapter 12: Two controversies: early treatment and occlusion. Am J Orthod Dentofacial Orthop. 2006;130(6):799-804.

[8] Wahl N. Orthodontics in 3 millennia. Chapter 13: Temporomandibular joint and orthognathic surgery. Am J Orthod Dentofacial Orthop. 2007;131(2):263-7.

[9] Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol. 1998;8(9):1558-64

[10] Garib DG, Raymundo Junior R, Raymundo MV, Raymundo DV, Ferreira SN. Tomografia computadorizada de feixe cônico (cone beam): entendendo este novo método de diagnóstico por imagem com promissora aplicabilidade na Ortodontia. Rev Dental Press Ortod Ortop Facial. 2007;12(2):139-56.

[11] Berco M, Rigali PH Jr, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop. 2009;136(1):17.e1-9; discussion 17-8

[12] Bernardes RA, Moraes IG, Hungaro Duarte MA, Azevedo BC, AzevedoJR, Bramante CM. Use of cone-beam volumetric tomography in the diagnosis of root fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(2):270-7.

[13] Brown AA, Scarfe WC, Scheetz JP, Silveira AM, Farman AG. Linear accuracy of cone beam CT derived 3D images. Angle Orthod. 2009;79(1):150-7.

[14] Damstra J, Fourie Z, Huddleston Slater JJ, Ren Y. Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. Am J Orthod Dentofacial Orthop. 2010;137(1):16.e1-6; discussion 16-7

[15] Fernandes TM, Adamczyk J, Poleti ML, Henriques JF, Friedland B, Garib DG. Comparison between 3D volumetric rendering and multiplanar slices on the reliability of linear measurements on CBCT images: an in vitro study. J Appl Oral Sci. 2014 Jul 4;0:0. [Epub ahead of print].

[16] Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants. 2004;19(2):228-31

[17] Lamichane M, Anderson NK, Rigali PH, Seldin EB, Will LA. Accuracy of reconstructed images from cone-beam computed tomography scans. Am J Orthod Dentofacial Orthop. 2009;136(2):156.e1-6; discussion 156-7.

[18] Lund H, Grondahl K, Grondahl HG. Accuracy and precision of linear measurements in cone beam computed tomography Accuitomo tomograms obtained with different reconstruction techniques. Dentomaxillofac Radiol. 2009;38(6):379-86.

[19] Menezes CC, Janson G, Cambiaghi L, Massaro C, Garib DG. Reproducibility of bone plate thickness measurements with cone-beam computed tomography using different image acquisition protocols. Dental Press J Orthod. 2010;15(5):143-9.

[20] Misch KA, Yi ES, Sarment DP. Accuracy of cone beam computed tomography for periodontal defect measurements. J Periodontol. 2006;77(7):1261-6.

[21] Mol A, Balasundaram A. In vitro cone beam computed tomography imaging of periodontal bone. Dentomaxillofac Radiol. 2008;37(6):319-24

[22] Mostafa YA, El-Beialy AR, Omar GA, Fayed MS. Four curious cases of cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2010;137(4 Suppl):S136-40..

[23] Özer SY. Detection of vertical root fractures of different thicknesses in endodontically enlarged teeth by cone beam computed tomography versus digital radiography. J Endod. 2010;36(7):1245-9.

[24] Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol. 2006;35(6):410-6.

[25] American Academy of Oral and Maxillofacial Radiology. Clinical recommendations regarding use of cone beam computed tomography in Orthodontics. Position statement by the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;116(2):238-257.

[26] Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. Am J Orthod Dentofacial Orthop. 2008;133(5):640.e1-5.

[27] European Commission. Cone Beam CT for dental and maxillofacial radiology: evidence-based guidelines. Luxembourg: SEDENTEXCT; 2012. (Radiation Protection; n. 172).

[28] Farman AG. Image gently: enhancing radiation protection during pediatric imaging. Oral Surg Oral Med Oral Pathol Oral Radiol. 2014;117(6):657-8.

[29] What is Cone-Beam CT and How Does it Work?

William C. Scarfe, Allan G. Farman, Dent Clin N Am 52 (2008) 707–730.

[30] Ludlow JB, Davies-Ludlow LE, Brooks SL, et al. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol. 2006;35:219–26 [erratum in: Dentomaxillofac Radiol. 2006;35:392].

[31] Ludlow JB, Davies-Ludlow LE, Mol A. Dosimetry of recently introduced CBCT units for oral and maxillofacial radiology. In: Proceedings of the16th International Congress of Dentomaxillofacial Radiology, Beijing, China 26–30 June, 2007. p. 97.

[32] Schulze D, Heiland M, Thurmann H, et al. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac Radiol 2004;33:83–6.

[33] Scaf G, Lurie AG, Mosier KM, et al. Dosimetry and cost of imaging osseointegrated implants with film-based and computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83:41–8.

[34] Dula K, Mini R, van der Stelt PF, et al. Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible. Eur J Oral Sci 1996;104:503–10.

[35] Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:106–14.

[36] White SC, Pharoah MJ. Oral radiology principles and interpretation. St. Louis: Mosby Elsevier, 2009:236–7.

[37] Farman AG. Self-referral: an ethical concern with respect to multidimensional imaging in dentistry? J Appl Oral Sci 2010.

[38] Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4 and 16-slice computed tomography: cone beam computed tomography systems and conventional tomography. Dentomaxillofac Radiol 2004;33:83–6.

[39] European Academy of Dental and Maxillofacial Radiol­ogy. Basic principles for use of dental cone beam CT. At: www.camosci.cz/public/files/pages/00000202\_basicprin­ciplesforuseofdentalconebeamct.pdf. Accessed: October 18, 2012.

[40] MacDonald-Jankowski DS, Orpe EC. Some current legal issues that may affect oral and maxillofacial radiology. Part 2: digital monitors and cone-beam computed tomog­raphy. J Can Dent Assoc 2007;73:507–11.

[41] Valentin J. The 2007 recommendation of the International Commission on Radiological Protection, publication 103. Ann ICRP 2007;37:1–332.

[42] Hashimoto K, Kawashima S, Araki M, Iwai K, Sawada K, Akiyama Y. Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT. J Oral Sci 2006;48:27–34.

[43] Bogdanich W, McGinty JC. Radiation worries for children in dentists ' chairs. The New York Times; Nov. 2010.

[44] American Academy of Oral and Maxillofacial Radiology Clinical recommendations regarding use of cone beam computed tomography in Orthodontics. Position statement by the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;116(2):238–257.

[45] Larson B.E. Cone-beam computed tomography is the imaging technique of choice for comprehensive orthodontic assessment. Am. J. Orthod. Dentofacial Orthop. 2012;141:402–411.

[46] Halazonetis DJ. Cone-beam computed tomography is not the imaging technique of choice for comprehensive orthodontic assessment. Am J Orthod Dentofacial Orthop. 2012;141(4):403–407.

[47] Van Vlijmen O.J., Bergé S.J., Swennen G.R., Bronkhorst E.M., Katsaros C., Kuijpers-Jagtman A.M. Comparison of cephalometric radiographs obtained from cone-beam computed tomography scans and conventional radiographs. J. Oral Maxillofac. Surg. 2009;67(1):92–97.

[48] Ludlow J.B., Gubler M., Cevidanes L., Mol A. Precision of cephalometric landmark identification: cone-beam computed tomography vs conventional cephalometric views. Am. J. Orthod. Dentofacial Orthop. 2009;136(3):312.e1–312.e10.

[49] Wriedt S., Jaklin J., Al-Nawas B., Wehrbein H. Impacted upper canines: examination and treatment proposal based on 3D versus 2D diagnosis. J. Orofac. Orthop. 2012;73(1):28–40.

[50] Katheria B.C., Kau C.H., Tate R., Chen J.W., English J., Bouquot J. Effectiveness of impacted and supernumerary tooth diagnosis from traditional radiography versus cone beam computed tomography. Pediatr. Dent. 2010;32(4):304–309.

[51] Joshi V., Yamaguchi T., Matsuda Y., Kaneko N., Maki K., Okano T. Skeletal maturity assessment with the use of cone-beam computerized tomography. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. 2012;113(6):841–849.

[52] Vizzotto M.B., Liedke G.S., Delamare E.L., Silveira H.D., Dutra V., Silveira H.E. A comparative study of lateral cephalograms and cone-beam computed tomographic images in upper airway assessment. Eur. J. Orthod. 2012;34(3):390–393.

[53] Ogawa T., Enciso R., Shintaku W.H., Clark G.T. Evaluation of cross-section airway configuration of obstructive sleep apnea. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 2007;103:102–108.

[54] Honey O.B., Scarfe W.C., Hilgers M.J., Klueber K., Silveira A.M., Haskell B.S. Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: comparisons with panoramic radiology and linear tomography. Am. J. Orthod. Dentofacial Orthop. 2007;132:429–438.

[55] Hintze H., Wiese M., Wenzel A. Cone beam CT and conventional tomography for the detection of morphological temporomandibular joint changes. Dentomaxillofac. Radiol. 2007;36(4):192–197.

[56] Schneiderman E.D., Xu H., Salyer K.E. Characterization of the maxillary complex in unilateral cleft lip and palate using cone beam computed tomography: a preliminary study. J. Craniofac. Surg. 2009;20:1699–1710.

[57] Albuquerque M.A., Gaia B.F., Cavalcanti M.G. Comparison between multislice and cone-beam computerized tomography in the volumetric assessment of cleft palate. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 2011;112(2):249–257.

[58] Schendel S.A., Lane C., Harrell W.E., Jr. 3D orthognathic surgery simulation using image fusion. Semin. Orthod. 2009;15:48–56.

[59] Kim S.H., Yoon H.G., Choi Y.S., Hwang E.H., Kook Y.A., Nelson G. Evaluation of interdental space of the maxillary posterior area for orthodontic mini-implants with cone-beam computed tomography. Am. J. Orthod. Dentofacial Orthop. 2009;5:635–641.

[60] Kim S.H., Choi Y.S., Hwang E.H., Chung K.R., Kook Y.A., Nelson G. Surgical positioning of orthodontic mini-implants with guides fabricated on models replicated with cone-beam computed tomography. Am. J. Orthod. Dentofacial Orthop. 2007;131:S82–S89.

[61] Qiu L., Haruyama N., Suzuki S., Yamada D., Obayashi N., Kurabayashi T., Moriyama K. Accuracy of orthodontic miniscrew implantation guided by stereolithographic surgical stent based on cone-beam CT-derived 3D images. Angle Orthod. 2012;82(2):284–293.

[62] Ye N., Li J., Zhang K., Yang Y., Lai W. Computer-aided design of a lingual orthodontic appliance using cone-beam computed tomography. J. Clin. Orthod. 2011;45:553–559.

[63] Cevidanes L.H., Heymann G., Cornelis M.A., DeClerck H.J., Tulloch J.F. Superimposition of 3-dimensional cone-beam computed tomography models of growing patients. Am. J. Orthod. Dentofacial Orthop. 2009;136(1):94–99.

[64] Garrett B.J., Caruso J.M., Rungcharassaeng K., Farrage J.R., Kim J.S., Taylor G.D. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am. J. Orthod. Dentofacial Orthop. 2008;134:8–9.

[65] Cevidanes L.H.S., Styner M., Profitt W.R. Three-dimensional superimposition for quantification of treatment outcomes. In: Nanda R., Kapila S., editors. Current Therapy in Orthodontics. Mosby-Wolfe; London, United Kingdom: 2010. pp. 36–45.

[66] Swennen G.R., Mollemans W., Schutyser F. Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging. J. Oral Maxillofac. Surg. 2009;67(10):2080–2092.

[67] Cevidanes L.H., Bailey L.J., Tucker G.R., Jr., Styner M.A., Mol A., Phillips C.L. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. Dentomaxillofac. Radiol. 2005;34:369–375.