Using CBCT in assessing treatment planning

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Abstract
Cone beam CT (CBCT) has become an increasingly important source of three dimensional (3D) volumetric data in clinical orthodontics since its introduction into dentistry in 1998. The purpose of this manuscript is to highlight the current understanding of, and evidence for, the clinical use of CBCT in orthodontics, and to review the findings to answer clinically relevant questions. It has therefore been recommended that CBCT be used in selected cases in which conventional radiography cannot supply satisfactory diagnostic information; which include cleft palate patients, assessment of unerupted tooth position, supernumerary teeth, identification of root resorption and planning orthognathic surgery. The need to use in other types of cases should be made on a case-by-case basis following an assessment of benefits vs risks of scanning in these situations.
Keywords:CBCT, Orthodontic treatment, Orthognatic Surgery, Root resorption
(Received Dec 2011; revised and accepted June 2012)

Cone beam computed tomography (CBCT) is a new advancement in computed tomography (CT) imaging that has begun to emerge as a potentially low-dose cross-sectional technique for visualizing bony structures in head and neck.

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CBCT was first adapted for potential clinical use in 1982 at the Mayo Clinic Biodynamics Research Laboratory[1].Initial interest focused primarily on applications in angiography in which soft-tissue resolution could be sacrificed in favor of high temporal and spatial-resolving capabilities. Since then, several CBCT systems have been developed for use both in the interventional suite and for general applications in CT angiography [2, 3]. Exploration of CBCT technologies for use in radiation therapy guidance began in 1992 [4, 5], followed by integration of the first CBCT imaging system into the gantry of a linear accelerator in 1999.[6]
The first CBCT system became commercially available for dentomaxillofacial imaging in 2001 (NewTom QR DVT 9000;Quantitative Radiology, Verona, Italy).[7]
In CBCT systems, the x-ray beam forms a conical geometry between the source (apex) and the detector (base).

This is in contrast to conventional fan-beam geometry, in which the collimator restricts the x-ray beam to approximately 2D geometry. In fan-beam single-detector arc geometry, data acquisition requires both rotation and z-direction translation of the gantry to eventually construct an image set composed of multiple axial sections. In CBCT systems using a 2D flat plan detector (FPD), however, an entire volumetric dataset can be acquired.[8]

A relatively low patient dose for dedicated dentomaxillofacial scans is a potentially attractive feature of CBCT imaging.[7] An effective dose in the broad range of 13–498 µSv can be expected, with most scans falling between 30 and 80 µSv, depending on exposure parameters and the selected field of view (FOV) size. In comparison, standard panoramic radiography delivers ~13.3µSv and multidetector CT with a similar FOV delivers ~860 µSv.[9,10]

Cross-sectional imaging affords overlay-free visualization of structural and anatomic relationships important for addressing many radiologic questions in orthodontics. The current standard of care for overlay-free imaging in orthodontics is conventional CT. [11] Low-cost office-based CBCT imaging has recently been explored for orthodontic applications, including assessment of palatal bone thickness, skeletal growth patterns, dental age estimation, upper airway evaluation, and visualization of impacted teeth.[12-17]

Although preliminary results are encouraging, established cross-sectional techniques such as conventional CT provide superior image quality of dental and surrounding structures for advanced orthodontic treatment planning.11 Low dosing requirements appear to remain a benefit of CBCT when compared with conventional CT, with a routine orthodontic CBCT study delivering an effective dose of ≤61.1µSv compared with 429.7 µSv for multisection CT. Lateral cephalograms deliver 10.4 µSv in comparison, though without the benefit of 3D structural visualization.[18]

Using CBCT in assessing treatment outcomes:

Maxillary expansion and airway dimension: Studies using CBCT on rapid maxillary expansion treated cases have revealed that although the total overall expansion that includes dental tipping, alveolar bone bending and skeletal expansion at the first premolar, second premolar and first molar were of similar magnitude, the skeletal expansion was greater in the anterior than posterior region of maxilla.17 Domann et al.8 studied 28 patients (19 female, 9 male) that required maxillary expansion therapy (with hyrax appliance). CBCT were taken at T1 (before maxillary expansion) and T2 (immediately after expansion). Results showed that there was a significant increase in interpremolar and intermolar distance with RME. In addition, the root angulation increased and this suggested that the movement was more tipping than translation. Another finding was that the thickness of the buccal plate decreases immediately after RME. Garrett et al.19 showed that of the total expansion obtained by hyrax: 38% was orthopaedic; 13% was due to alveolar bending; and 49% resulted from dental tipping. It is therefore likely that most post-expansion relapse occurs owing to rebound from alveolar bending and dental tipping because these two modalities of expansion are hard to retain. Pangrazio et al. 20 stated that although bonded expanders and banded expanders expanded maxilla similarly, both appliances equally increased the skeletal and soft tissue dimension of nasal cavity and maxillary sinuses volume, but their dental effects aren't the same. In the banded expansion, more dental tipping and alveolar bending occurred at the level of the first molars. However the posterior airway volume didn't significantly change with either method of expansion. This evidence was confirmed by Reibeiro21 and Zhao22. "Although narrow oropharyngeal airways in growing patients with maxillary constriction but there was no evidence to support the hypothesis that RPE could enlarge oropharyngeal airway volume." Zhao et al. stated 22. Reibeiro et al 21 believed that changes noted in the oropharynx maybe due to the lack of a standardized position of the head and tongue at the time of image acquisition. In addition, buccal crown tipping was accompanied by a decrease in buccal bone thickness and buccal marginal bone height

Management of cleft lip and/or palate patients:

CBCT can help orthodontists to asses cleft lip and/or palate (CLP) defects and its complications accurately and aid him to decide properly. For example CBCT can verify the thickness and level of alveolar bone around the teeth adjacent to the cleft and give accurate information about the graft. Garib23 studied on patients with complete bilateral cleft lip and palate prior to bone graft surgery and orthodontic intervention. The sample comprised 10 patients with complete bilateral cleft lip and palate (5 males and 5 females) in mixed dentition. Results showed that despite the presence of the clefts, the teeth adjacent to the cleft generally present a good periodontal bone support during the stage of mixed dentition. Buccal and mesiodistal orthodontic movement as well as rotational movements of maxillary anterior teeth before alveolar bone graft should be avoided or carefully conducted in these patients, because there is thin alveolar bone plate around the teeth adjacent to the clefts. CBCT are used to assess eruption path of the permanent maxillary canine. Oberoi et al.24 applied CBCT to evaluate the eruption path of the permanent maxillary canines during a 1-year period after secondary alveolar bone grafting. He found that most canines on both the cleft and non-cleft sides moved incisally, facially, and mesially. Also, he found that twelve percent of the canines on the cleft side required surgical exposure to appear. Eighty percent of the canines had less than half root development at the time of bone grafting. The amount of root development did not affect the outcome in terms of eruption amount or direction. Schneiderman et al. 25 compared the dimensions of the maxillary complex in three dimensions in the treated patients with CLP and normal young adults. He stated that significant differences between the patients with unilateral CLP and control subjects (combined sex samples) were found in palate length, anterior palate thickness, overall sagittal maxillary length, and premaxillary height. The body of the maxilla and its heights appear less affected. However, they said that these methods and preliminary findings laid the groundwork for larger scale and prospective studies.

CBCT and orthognatic surgery:

Many studied have been performed about the use of CBCT in orthognatic surgery. One of these fields is the effect of orthognatic surgery on the airway. Park26 evaluated the volumetric change of the upper airway space in 36 Class III patients who had undergone bimaxillary surgery or isolated mandibular setback, and, further, to analyze the relation between post-surgical stability and airway change using cone-beam computed tomography. A three-dimensional (3D) CBCT examination was performed at three stages: T0 (before surgery), T1 (an average of 4.6 months after surgery), and T2 (an average of 1.4 years after surgery). He found that the volumes of the oropharyngeal and hypopharyngeal airways decreased significantly 4.6 months post-surgery in the mandibular setback group, and these diminished airways had not recovered 1.4 years post-surgery. In the bimaxillary surgery group, the volume of the oropharyngeal airway also decreased. But Hong27 stated that although pharyngeal airways showed narrowing after both mandibular setback surgery and bimaxillary surgery but the amount of changes in the anteroposterior dimension and cross-sectional area on the posterior nasal spine plane and the length of the pharyngeal airway showed significant differences between the 2 groups. The amount of narrowing of the pharyngeal airway was smaller in patients undergoing bimaxillary surgery than in the patients undergoing mandibular setback surgery. On the other hand Hernandez et al.28 showed pharyngeal airway volume increased after forward movements of the maxilla or mandible, or both but the influence of mandibular advancement on the pharyngeal airway volume was greater than the effect of the forward movement of the maxilla. Another issue was how much the results of CBCT and OPG was similar to each other. There was a weak, but statistically significant, correlation between the linear and volume measurements in the nasopharyngeal and oropharyngeal regions but not in the hypopharyngeal region. Sears et al 29 investigated the correlation between linear (data from lateral cephalometry) and volume (data from CBCT) measurements after orthognatic surgery. He obtained lateral cephalograms and CBCT scans at 3 points: preoperatively, within 1 month postoperatively, and after 6 months postoperatively. The nasopharynx, oropharynx, and hypopharynx were segmented on both the radiograph and the CBCT scan for each patient. Of the 20 patients, 13 were female and 7 were male. The mean age at surgery was 23.85 years (range 14 to 43). Of the 20 patients, 6 underwent maxillary advancement only, 8 underwent mandibular advancement with or without genioplasty, and 6 underwent 2-jaw surgery or mandibular setback. Results displayed that a weak, but statistically significant correlation existed between the linear and volume measurements in the nasopharyngeal and oropharyngeal regions but not in the hypopharyngeal region. The mandibular advancement with or without genioplasty group (n = 8) showed a correlation in the nasopharyngeal and oropharyngeal regions. For the combination/setback procedures (n = 6), a correlation was found only in the oropharyngeal region. All other comparisons between the linear and volume measurements did not correlate. Additionally, no correlations were found between the linear and volumetric change in airway size between 6 months postoperatively and preoperatively, except for the oropharyngeal region.

CBCT's role in facial soft tissue prediction:

Prediction of soft tissue aesthetics is important for achieving an optimal outcome in orthodontic treatment planning. Previously, applicable procedures were mainly restricted to 2-D profile prediction.30 in one study, Bianchi31 studied on 10 patients with craniomaxillofacial deformations. They underwent CBCT before surgery, by Using the SurgiCase CMF software, the data were reconstructed in 3 dimensions, and various osteotomies were simulated in a 3-dimensional virtual environment by applying different surgical procedures. At 6 months after surgery, the patients repeated CBCT again. After superimposition, he found that CBCT simulations defined an average absolute error of 0.94 mm, a standard deviation of 0.90 mm, and a percentage of error less than 2 mm of 86.80%.

Impacted teeth:

Impacted and transposed teeth are possibly the most common reason for use of CBCT imaging in orthodontics.17 Maxillary canine is the second most commonly impacted tooth, after the third molars. The reported incidence ranges from 0.8% to 2.8%, depending on the population examined. Proper localization of an impacted tooth is required to make an accurate diagnosis, determine proper surgical access, and plan the direction of orthodontic recovery forces.32

Haney et al.32 established one study for evaluation the accuracy of the 2d and 3d radiography in localization of the maxillary impaction canine. Twenty-five consecutive impacted maxillary canines were identified in the patients seeking orthodontic treatment. Two sets of radiography were taken. The first set of radiographs consisted of traditional 2-dimensional (2D) images including panoramic, occlusal, and 2 periapical radiographs. The second set comprised prints of 3-dimensional (3D) volumetric dentition images obtained from a cone-beam computed tomography scan. Then seven faculty members completed a questionnaire for every impacted canine and diagnostic radiographic modality (2D and 3D). Results of this study showed there were 21% disagreements between faculty members (or discordance) in the perceived mesiodistal cusp tip position and 16% difference in the perceived labiopalatal position. In the perception of root resorption of adjacent teeth, there was 36% lack of congruence. Twenty-seven percent of the teeth that were planned to be left, recovered, or extracted with the 2D radiographs had different treatment plans when the judges viewed the 3D CBCT images. The study finally concluded that the clinicians' confidence of the accuracy of diagnosis and treatment plan was statistically higher for CBCT images. These results showed that 2D and 3D images of impacted maxillary canines can produce different diagnoses and treatment plans.

Root resorption and CBCT:

Resorption of the root of the maxillary incisors during ectopic eruption of the maxillary canines is not an uncommon phenomenon and must be considered in all patients with seriously ectopic eruption of the maxillary canines. The root of the lateral incisor is the most commonly affected by resorption, although the central incisors can be affected. Incisor resorption has been reported to occur more frequently in women, with the female to male ratio being reported as 2:1, 4:1 and 10:1. However, no sex differences have been found in the severity or location of root resorption. [7]

Root resorption of the maxillary incisors is often difficult to identify on intra-oral radiographs, mainly due to the overlapping of the incisors by the ectopic canine. Cone-beam computed tomography (CBCT) is superior to conventional X-ray methods for the assessment of incisor root resorption associated with ectopically positioned maxillary canines, as it eliminates the blurring problem of conventional tomography and increases the perceptibility of root resorption substantially. It was found that 50% more resorptions are detected with CT compared with conventional radiographic methods.33 Early detection and assessment of the extent of resorption is, therefore, of fundamental importance if preventive and early corrective measures are to be taken in order to reduce later complications and to prevent the resorption from getting worse.

Many study established for comparing CBCT and other radiographic in diagnosis of resorption. Kumar et al34 used a porcine mandible to support 10 human maxillary central incisors. He generated CBCT and digital periapical radiographic images before and after creation of standardized and sequentially larger root defects on either the mesial or the lingual root surfaces. Then the images were randomly labeled and evaluated by 3 examiners. Each image was classified according to defect size (0, none; 1, mild; 2, moderate; 3, severe). He stated from results that:

- The location of the root defect (mesial vs lingual) had no significant effect on the evaluation of defect size.
- Both periapical radiographs and CBCT were slightly better at detecting lingual defects than mesial defects (75% vs 65% and 65% vs 60%, respectively), but these effects were not statistically significant
- Examiners using CBCT images tended to overestimate defect sizes and Examiners using periapical radiographs tended to underestimate defect sizes.

Finally He concluded that there was no difference in accuracy of identifying defects between periapical radiographs and CBCT images. But Estrela35 stated CBCT seems to be useful in the evaluation of IRR (internal root resorption), and its diagnostic performance was better than that of periapical radiography.

On the other hand, Patel et al.'s study36 showed CBCT was effective and reliable in detecting the resorption lesions than intraoral digital radiography. He took CBCT and digital intraoral radiography of patient with internal resorption (n = 5), external cervical resorption (n = 5) and no resorption (controls) (n = 5). He stated although digital intraoral radiography resulted in an acceptable level of accuracy, but CBCT was more effective and reliable in detecting the presence of resorption lesions. One study showed that apical root resorption after orthodontic tooth movement is underestimated when evaluated on OPG.[37]

Incidental findings, missed findings and medico-legal implications:

An additional question that requires further study is the capability of the orthodontists to identify non-orthodontically relevant findings and to make appropriate referrals when needed. Lack of the recognition of incidental lesions can have substantial medicolegal ramifications. In contrast, the potential for inadvertent diagnosis of false-positive findings by the untrained eye have the potential to add unnecessary costs to healthcare, as well as cause unnecessary anxiety to the patient and family. In a recent study17, it was shown that orthodontists and orthodontic residents missed approximately 67% of lesions and had a 50% false-positive detection rate in CBCT images. Following a 3 hours training session by an oral maxillofacial radiologist, the error rate in these two measures dropped to 33% and 30%, respectively. This error rate is relatively high compared with historical gold standard data on lesion detection by trained radiology specialists. These findings suggest that CBCT taken for orthodontic purposes should be read by an oral maxillofacial radiologist and that increased training in viewing normal and abnormal anatomy in CBCT images would provide an additional valuable mechanism for orthodontists to further identify important components relevant to their diagnosis.

Temporary anchorage devices:

The use of skeletal anchorage, such as self-drilling miniscrews or microscrew implants, is growing in popularity because of its ability to provide absolute anchorage. Correct placement of implants is a basic requirement.

Insertion of mini-implants in the alveolar process between the roots of the teeth is a critical procedure. Major complications can include damage to adjacent tooth roots38. Fabbroni et al.39 reported that the incidence of screw/tooth contact in the placement of transalveolar screws was 27.1 per cent. Lin et al.40 used CBCT to evaluate the cortical bone thickness at upper molar miniscrew sites. Sixty Angle's Class II division I patients were involved in this study (30 males and 30 females), measurements of cortical bone thickness were done with cone beam computer tomography (CBCT) scanning. The contact point of upper second premolar and upper first molar was chosen for center of coordinate. Totally 20 layers of cortical bone were measured every 1 mm. They at last concluded that:

- The cortical bone thickness gradually increased from occlusal to gingival directions in this area;
- The cortical bone was thicker in male than in female at the same level. (The average cortical bone thickness was 2.12±0.72mm in male, and 1.86±0.83mm in female (above 7th layer).)
- The cortical bone thickness had no significant difference between left and right side.

Qiu et al.41 stated No root damage was found when surgical stents were fabricated according to 3D CBCT image, whereas four of 10 miniscrews in his study contacted with roots in the freehand group.

Conclusion:

Although CBCT gives us accurate diagnostic information in many fields of orthodontics such as cleft palate patients and impacted teeth, but its use is recommended primarily in case selection in which conventional radiography cannot supply satisfactory diagnostic information.

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