THREE-DIMENSIONAL CONE BEAM COMPUTED TOMOGRAPHY IN ORTHODONTICS

Dr Maulik Rao*

Abstract:
The use of 3-dienzional (3D) diagnostic records can be an extremely valuable tool, as these records can accurately reproduce a patient dataset in secondary environment, and when appropriately interfaced allow the practitioner the ability to create and manipulate these records as a 3D “virtual patient”. The relative ease of reconstructing the 3D virtual represents the right step forward in the orthodontic diagnosis and treatment planning. These advancements in technology has pushed the “learning curve” for clinicians and allowed tools to be created for future which one day will replace the current methods of orthodontic record taking.

Key Words: Orthodontic treatment, 3D Cephalometry, Future direction.

Introduction
As we progress, the truth of today becomes the myths of tomorrow. Since the early 1930s the classical orthodontic patient documentation consisted of a lateral head film, orthopantomogram, facial and dental photographs, and plaster casts.1 Practitioners of a scientific discipline are generally resistant to accept a new paradigm, nonetheless a paradigm shift has occurred, a veritable explosion of new ideas and information has occurred, leading to rapid advances in the field.

The use of 3-dimensional (3D) diagnostic records can be an extremely valuable tool. These records can accurately reproduce a patient dataset in a secondary environment, and when appropriately interfaced, allow the practitioner the ability to create and manipulate these records as a 3D “virtual patient.” Both the practitioner and patient can benefit from the development of these new technologies because they can provide a more accurate platform for diagnosing and treatment planning, and be a valuable tool for patient education.2

The advent of 3-dimensional (3D) radiographic imaging with cone beam computed tomography (CBCT) has led to a multitude of clinical applications across all dental disciplines.

Many different names have been suggested for this technology. Although functional nomenclature, such as digital volume tomography or cone beam volumetric tomography (or simply volumetric tomography or cone beam imaging), have been proposed in an effort to differentiate it from its high-radiation, conventional medical computed tomography (CT).3

During a CBCT scan, many single 2D snapshot images are captured from predefined angles as the machine moves through a single iso-centric rotation of the x-ray source/sensor unit.

These raw images are then computationally compiled into a 3D dataset with the use of specialized reconstruction algorithms. The resultant overlap-free “3D image” still offers many advantages over standard 2D x-ray radiographs, such as:

- 3D representation of dental and craniofacial structures;

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*Post Graduate Student
Modern Dental College and Research Centre,
Indore,(M.P)

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● Custom image reformatting to provide optimal visualization from different angles and perspectives;
● Orthogonal images that do not contain magnification errors or projection artifacts;
● Management of superimpositions;
● Interoperability in Digital Imaging and Communications in Medicine (DICOM) format;
● Generation of data that can be used in other diagnostic, modeling, and manufacturing applications; and
● Radiation exposure within a similar range of other dental radiographic imaging devices, which is generally an order of magnitude lower than that of medical CT devices.  

There are numerous CBCT systems currently on the market, with an estimate of more than 30 CBCT device manufacturers worldwide. Configurations vary from system to system, with differences in: (1) patient position during image acquisition (supine position similar to medical CT devices, stand-up configurations patterned after common panoramic machines, seated units, or portable systems developed for intraoperative examination and mobile scanning centers), (2) image capture sensor type, (3) field of view (FOV), (4) x-ray generator, and (5) reconstruction algorithm and visualization software.

This article describes a comprehensive analysis of the CBCT volume for orthodontic diagnosis and treatment planning, including the following:

● Lateral and frontal cephalometric views;
● 3D skeletal views and 3D review of the dentition;
● Alveolar ridge shape and volume;
● Temporomandibular joints;
● Sinuses and airway;
● Facial analysis;
● cleft lip and palate; and
● Facial modeling and therapeutic applications.

3D Cephalometry

Cephalometric analysis in orthodontics is an essential diagnostic tool for evaluation of craniofacial morphology. Medical CT provides this ability and is used in the management of craniofacial anomalies; however, its cost, limited accessibility, and relatively high radiation dose preclude its use for common orthodontic patients. With the introduction of CBCT, 3D visualization is available without the major limitations associated with medical CT.

Figure 1. CBCT-generated lateral cephalogram (A) and panoramic radiograph (B). Advantages include the ability to excise extraneous anatomical structures, thereby eliminating superimpositions.
Skeletal Views

The volumetric 3D skeletal view is a new method to visualize the relationships of maxillomandibular structures relative to the cranial base (Fig 2). These images allow surface inspection of the osseous morphology of the jaws and external soft tissue while preserving the internal root position, inferior alveolar nerve, and airway information. A fundamental understanding of craniofacial growth and development is very important to orthodontists for predicting treatment outcomes and stability.

Figure 2. CBCT DICOM data volumetric reconstruction of the maxillomandibular relationship relative to cranial base.

For example, a conventional lateral cephalogram may reveal remodelling changes on the anterior and posterior surface of the vertical mandibular ramus but only CBCT can show transverse changes using the same dataset without additional x-rays (Fig 3).

Figure 3. Segmentations of mandibular structure showing transverse dimensions. (A) Lateral, (B) oblique, and (C) transverse.

Figure 4. Volumetric views of impacted canines and their positional relationship to adjacent teeth in both maxillary and mandibular arches (A) Frontal and (B) oblique views to better visualize the impacted canine crown and its root.
Alveolar Ridge Shape and Volume

In this category, CBCT offers enormous advantages compared with conventional images for the evaluation of dentoalveolar arch form, alveolar volume, lesions within the alveolus, and cortical bone density. A recent study described the use of CBCT occlusal images to select arch wire forms (Wolff M, Mah J, manuscript in preparation). Arch form tracings are typically made at the height of the alveolus, but can be modified according to the user’s preference. The arch forms can then be superimposed to reveal discrepancies or compatibility and can be printed at full size for selection and fabrication of arch wires. Other emerging uses of these images are for arch-length measurements and identifying tooth size discrepancies using the Bolton analysis.

Temporomandibular Joints

CBCT is particularly useful for evaluation of the temporomandibular joints. The joints may be visualized in volumetric views as well as sectional views (Fig 5). Within the latter, the TMJ images can be obtained in planes parallel or perpendicular to the long axis of the condyle in addition to the conventional coronal and sagittal planes. This provides comparability of TMJ images of the bony components on all planes. Developmental and pathologic changes can be detected using the lateral views. The central lateral view defines the true position of the condyle in the fossa, which often reveals possible displacement of the disk in the joint. Coronal views of TMJ are difficult to obtain precisely and clearly with conventional techniques. High resolution and unobscured coronal views of the joints are available with CBCT.
Sinuses and Airway Evaluation

Use of CBCT for the assessment of the sinuses and airway is emerging as a major application for the technology (Fig 6). This information is particularly relevant to the orthodontist because mouth breathing and consequent airway obstruction is considered an etiology of malocclusion. Unfortunately, the traditional orthodontic records do not allow for comprehensive evaluation of the airways.

Figure 6. A virtual representation of a complete airway passage (nasopharynx, oropharynx, and hypopharynx) segmented from a CBCT DICOM dataset.

Facial Analysis

A conventional facial photograph is a simple 2D representation that is not correlated with the supporting skeleton. New software features now enable facial photos (either 2D or 3D) to be morphed onto a DICOM dataset using nodal mapping algorithms, and the 3D volume can generate a simulated 3D projection of the face in any frontal, lateral, or user-defined view of the face. By changing the translucency of the image, one can determine the specific relationship of the soft tissues to the skeleton (Fig 7).

Figure 7. Facial photos superimposed onto a 3D volumetric skeletal rendering. Nodal mapping and stereophotogrammetry morphing enable the photos to be visualized and be manipulated in 3D.

This has significant implications in the planning of tooth movements, orthognathic surgery, or other craniofacial therapies that could alter facial appearance.

Cleft Lip and Palate (CLP)
CBCT offers many unique advantages for imaging of patients with CLP. The rapid acquisition time ranging from 5.7 to 40 seconds is a tremendous advantage for young patients and for patients who have difficulty remaining stationary. The much lower radiation dose for the patient is favorable for subsequent imaging sessions and decreases the total cumulative radiation dose compared with serial medical CT scans. Medical CT has been used for visualization of cleft palates and other anomalies but there is concern for single and cumulative exposure to young patients. Recent improvements in CBCT features of resolution, soft-tissue contrast, and specialized reconstruction algorithms for the head and neck region, along with a significantly reduced radiation exposure, make it a preferred imaging modality of choice for CLP patients.

Modeling and Therapeutic Applications

Digital Study Models

3D study models of the dentition can be obtained by intra- and extraoral imaging technologies. Intraoral scanning devices can accentuate detailed crown anatomy but is limited regarding the location or relationship of the roots of the teeth and their relationships with other anatomic structures. CBCT imaging offers study models that display individual crowns and roots, although the accuracy of the crowns can vary depending on various factors, such as imaging device, patient movement and metallic artifacts.

Future developments to produce 3D dynamic models can be used to analyse and predict the interaction between structure and function. Customized patient representation using dynamic 3D modeling of motion will become a valuable tool in advanced dental applications.

Future Directions

These advancements in technology have added valuable information to this topic of interests to orthodontists. It has pushed the “learning curve” for clinicians and allowed tools to be created for the future. Many 3D imaging devices are available for soft tissue and hard imaging. New techniques and sophisticated software tools now allow clinicians to manipulate the images and to make them relevant to the clinical setting.

CONCLUSIONS

The relative ease of reconstructing the 3D virtual represents the right step forward in orthodontic diagnosis and treatment planning. With the cost and increase in speed for acquiring and reproducing images, 3D virtual record will one day replace current methods of orthodontic record taking.

References: