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A Modern Era In Orthodontic Diagnosis And Treatment Planning : Cone Beam Computed Tomography

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Abstract
With the introduction of 3 D imaging in the field of dentistry, this technology has generated a lot of interest in various applications in orthodontics. As orthodontic treatment revolves around correcting a malocclusion in all 3 planes of space, the earlier use of 2 D radiographs limited our view of anatomical structures greatly. In orthodontics cone beam computed tomography (CBCT) can be of great use in the study of development of dentition, limits of tooth movement, assessment of airway, craniofacial morphology and superimposition. Many orthodontic treatment procedures are geared toward resolving conditions that cannot be appraised adequately by using conventional two-dimensional (2-D) radiographs. In addition, many relationships of the craniofacial complex, such as the position of the mandibular condyles in the temporomandibular fossa with respect to the occlusal scheme and the association of airway abnormalities to craniofacial morphology, cannot be evaluated with conventional imaging approaches. In this article we would like to shed light on the current practices in orthodontics and how earlier used technology had its limitations. The authors would like to describe how these limitations can be overcome with the introduction of CBCT in orthodontics.

Key Words
Cone beam computed tomography (CBCT) in Orthodontics,CBCT, airway assessment, craniofacial morphology, Rapid prototyping.

Introduction

The speciality of orthodontics has been eager to note the three dimensional nature of malocclusion and with recent advances in three-dimensional (3-D) imaging, this technology has generated extensive fields of application in dentistry. In this article, we want to reflect on the current practices in orthodontics. There have been limitations of earlier used technology which have influenced the clinical routine of orthodontists. We focus on the practical applications of CBCT that lay its importance in comprehensive orthodontic care. A web based search was conducted in all the websites of the major orthodontic journals from their earliest edition to the latest and a search was conducted in medline wherein the keywords “Cone beam computed tomography” and “orthodontics” were used. A manual search was also done among physically available literature. A large number of clinical studies were found wherein CBCT was used to observe clinical results but a few articles were present which reviewed all the clinical studies conducted and summarized how CBCT is beneficial in the field of orthodontics.

Historical Development

The clinical CT scanner was introduced by Sir Godfrey N. Hounsfield in 1967. The data acquisition depended on translate-rotate parallel-beam geometry. Pencil beams of X rays were directed at a detector opposite the source and the transmitted intensity of photons incident on the detector was measured. The translation and rotation of the gantry would capture x ray attenuation data systematically from multiple points and angles. Data acquisition in CT imaging has evolved through four generations of acquisition geometries. First- generation scanners used parallel pencil beams of x-rays and included translation and rotation of the source and a single- detector apparatus. Second generation scanners introduced the fan-beam x-ray geometry and used a single detector linear array. Third generation scanners came with single- detector arc in conjunction with fan-beam x ray geometry. Fourth generation scanners used the fan- beam of x rays and a circular detector array. Nowadays multidetector helical CT (MDCT) scanning is most frequently used.[1]

Cone beam computed tomography (CBCT) scanners were first introduced in 1982. They employ an x-ray beam which is a thin collimated cone between the source (apex) and the detector (base) which is a planar sensor similar to that used in digital cameras. All data is acquired by a single pass of the emitter around the subject and eliminates the need for a movable gantry. Cone beam technology was first introduced in the European market in 1996 by QR s.r.l. (NewTom 9000) and into the US market in 2001.[2]

Mechanical aspects of CBCT

Both MDCT and CBCT provide raw data that can be analogized into a digital block of voxels which can be reconstructed to produce a 3D volumetric representation of any part of the head so that clinicians can see their patients as never seen before. Secondary reconstruction can produce projection images of views such as OPGs, lateral and frontal cephalogram or individual periapical images. Planar images through any section from different perspectives such as sagittal, coronal and cross sectional can be generated without confounding overlap.

CBCT in Orthodontics

As a 3D rendition, CBCT offers an undistorted view of the dentition that can be used to accurately visualize both erupted and non-erupted teeth, tooth root orientation and anomalous structures that conventional 2D radiography cannot.

The other applications in orthodontics include study of development of dentition, limits of tooth movement, assessment of airway, craniofacial morphology and superimposition.

Development of Dentition

The development of the primary and permanent dentition is one of the most complicated processes and an in-depth evaluation of this 3-D process presents a challenge to clinicians who use conventional imaging, particularly if there are deviations in tooth numbers, shapes, sequence and positions. The complexity of dental development and its variations are mostly lost in a 2-D record.

For example, diagnosis and prognosis of impacted maxillary canines with respect to length of treatment and complexity is restricted when clinicians obtain panoramic radiographs.[3] CBCT offers an undistorted view of the dentition that shows the details of individual dental morphology, including intricate features of tooth roots, and missing, supernumerary and anomalous teeth, as well as the 3-D spatial orientation of the teeth and roots.

CBCT imaging puts the clinician in a much better position than conventional imaging to evaluate eruption patterns and their variations.[4] The information provided can help clinicians study the process of dental development and individualized planning for eruption guidance, selective extractions and custom biomechanical approaches.

Advances in computer software have allowed for the production of interactive digital models (Anato- Model, Anatomage, San Jose, Calif.) from the CBCT data volume (viewable CBCT data).[5] The advantages of using these models include eliminating the need to take impressions, and that during visualization the clinically visible crowns appear with the tooth roots and surrounding alveolar bone. Conventional radio - graphic imaging, such as panoramic and small dental radio graphs, has limitations - such as magnification, distortion, superimposition, limited perspective and lack of resolution - when it is used to visualize root resorption.[6],[7],[8]

Root resorption can be observed readily in CBCT images, and the image clarity allows clinicians to classify the type of root resorption. For teeth with multiple roots, resorption can be localized to a specific root.

Another advantage is that the occlusal scheme is related to the position of the condyles within the temporomandibular fossa. No other imaging modality offers this feature. Clinicians can view the soft tissues of the face with respect to both the dentition and skeletal structure, and they can compare the occlusal views of the arches with the shape of the alveolus. The accuracy of dental measurements of overjet, overbite and arch length from these virtual models is comparable with that of other digital study models produced from impressions.[9] There is ongoing research and development in the area of manufacturing dental appliances from dental models developed by means of CBCT.

Limits of tooth movement

The multidimensional nature of volumetric imaging allows for comprehensive visualization of the dentition and recognition of some of the limits of tooth movement. Many situations cannot be visualized by means of traditional orthodontic records. Enostosis, condensing osteitis, dense bone island and focal apical osteopetrosis[10] are radiopaque lesions noted near the apexes of teeth, and they appear to have no causative factors. A high percentage (88 to 100 percent) of these lesions occur in the mandible[11], and the most common extraoral positions are the pelvis and long bones.[12] These lesions may not be visualized readily on panoramic radiographs, and they can prevent tooth movement. In these situations, space closure and the establishment of proper torque may not be possible, and, if biomechanical forces are applied to move the adjacent tooth against the dense lesion, external apical root resorption may result.

A more common situation is that of a patient with a deep bite. Common treatments include the use of biteplates to extrude posterior teeth or intrusion arches to intrude the maxillary anterior teeth to reduce the degree of overbite. A cross-sectional view of the incisors can reveal the vertical dimension of bone apical to the maxillary central incisors and the limited space for intrusion. In these situations, extrusion of the posterior teeth to address the deep bite would be a more appropriate treatment and would prevent damage to the apices of the central incisors against the dense bone of the nasal floor.

Airway Analysis

The causal relationship between airway disorders and malocclusion was described as early as 1935.[13] This relationship is a common cause of malocclusion and leads to the classic appearance of adenoid facies. Perhaps as a result of the lack of diagnostic instruments in this area, the focus on patient airway assessment seems to have subsided until CBCT arrived and aided in the evaluation of airways.

The results of a retrospective review of 500 orthodontic patients showed that 18.2 percent of the patients had airway-related problems.[14] Lateral cephalograms have been used to analyze the airway. Despite the number of studies in this area, the overall strength of these studies is weak, owing to small sample sizes, lack of control participants, inconsistent head positions and poor study designs.[15] As a result, there are no effective anatomical measures from lateral cephalograms that are correlated with sleep apnea. In contrast, use of 3-D imaging (magnetic resonance imaging [MRI]) revealed more specific anatomical findings in patients with apnea. It seems that the predominant factor causing airway movement is the thickness of the lateral pharyngeal muscular walls, as opposed to the fat pads in this area.[16] Chen and colleagues found that the anteroposterior and lateral diameters of the RP region, as well as the smallest area of the RP region, are significantly smaller in patients with obstructive sleep apnea (OSA).[17] Although the gold standard for diagnosis of OSA is a sleep study,[18] 3-D imaging can be an adjunctive diagnostic tool. Within the CBCT data, there is distinction between the soft tissue of the pharynx and the airway space. This distinction allows for relatively straightforward segmentation of the airway in the performance of volumetric analysis.

Craniofacial Morphology

Conventional cephalometrics is limited by a number of factors, including x-ray beam geometry resulting in image magnification, left and right side differences, and head positioning. The physics of lateral cephalograms impose substantial constraints on the resultant image, which can reflect a magnification error.[19] The side closer to the film is magnified less than the side further from the film, which causes the double border of the mandible that can be seen on lateral cephalograms. It becomes a clinical judgment to estimate the norm of this double border and whether an increased or decreased double border signifies asymmetry.

There are no magnification issues with CBCT because the 3-D object is reconstructed from raw data by means of a mathematical algorithm that has the ability to calculate and eliminate the magnification factor even though the x-rays are not parallel. The isotropic images generated by CBCT facilitate visual observations of asymmetries and abnormalities, which can be confirmed by using linear and angular measurement tools included in 3-D imaging software packages. These measurements are reliable and anatomically accurate.[20] The CBCT data set can be reformatted to generate a CBCT-reconstructed lateral cephalogram so that conventional measurements can be made and compared with existing 2-D norms. The advantages of using CBCT-reconstructed lateral cephalograms include the ability to digitally reorient the head position in cases in which the patient did not undergo scanning with the proper head position and the ability to enhance the image quality by virtually sculpting away extraneous superimposing skeletal structures that are not relevant to the lateral cephalometric measurement process. In addition, separate images can be created of the left and right sides for assessment of asymmetries. Software developers are starting to incorporate a way to identify anatomical and cephalometric landmarks on the volumetric data set. This is a starting point for the ability to use new anatomical landmarks not visible on 2-D cephalograms and to measure new distances and angles that will give insight into the growth and development of the craniofacial complex. With this possibility in mind, it also is important to think beyond conventional metrics of measuring distances and angles. Using the concept of morphometrics, clinicians can construct a 3-D norm and then superimpose individual 3-D scans on this norm to determine variations and standard deviations. Clinicians can quantify localized differences by using a color-mapping scheme to determine magnitude of difference. Pretreatment and posttreatment superimpositions also can be added to evaluate tooth movement.

Anteroposterior cephalograms are another radiographic tool that can be used to identify transverse asymmetries. However, slight deviations of head position can produce substantially varying results on conventional radiographs. CBCT-reconstructed anteroposterior cephalograms can reorient the head position after the initial scan and have the ability to remove extraneous superimposing structures (for example, vertebrae) for better image clarity.

Superimpositions

Assessing treatment outcomes is important when documenting treatment changes and research. The approach to lateral cephalometric superimposition used by the American Board of Orthodontics[21] involves cranial base registration on the outline of the sella turcica and the best fit of the anterior cranial base bony structures, using the lingual curvature of the palate with the best fit on the maxillary bony structures, and registration on the internal cortical outline of the symphysis with the best fit on the mandibular canal for superimposition of the maxilla and mandible, respectively. Clinicians who have performed this type of cephalometric superimposition are aware that it is a challenging process owing to issues related to image fidelity, landmark selection and identification.[22] Because the method is limited to superimposition of lateral cephalograms, the information is only from the sagittal plane.

The introduction of CBCT allows clinicians to perform superimpositions in three dimensions and has eliminated some of the errors that occur with traditional lateral cephalometric superimposition. Recently, a method for superimposition of CBCT images that does not first require segmentation or landmark selection was developed that is accurate, fast and automatic.[23] Because this method eliminates the need for segmentation and selecting landmarks, the errors associated with these steps are eliminated, thereby reducing the overall cumulative errors. Common weaknesses of many outcomes studies are image fidelity and method errors in the superimposition process, leading to confounding and often conflicting results. The application of CBCT and this new method of assessing treatment outcomes have the potential to settle many controversies in orthodontics, such as the mechanism of functional appliances, nonextraction philosophies, molar distalization, temporomandibular effects and others.

Rapid Prototyping

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three dimensional computer aided design data. This is usually done using 3D printing or additive layer manufacturing technology. This new age technology has found its way in the field of orthodontics as a tool in diagnosis and treatment planning. CBCT allows us to scan our area of interest at axial slices no thicker than 1mm- the thinner the slice the higher the quality of the model. The images are saved as DCM (digital imaging and communication in medicine) files in a CD-ROM or zip drive. Alternatively it can be directly forwarded to the company via the internet. The DCM files are imported into the CT image processing software which builds up the image and constructs the virtual 3D model. This technology can help us plan and execute orthognathic surgeries by helping us recreate a scale model of our patients' orofacial region and aid in planning and executing the treatment plan on the model. This can also aid us in communicating with our patients better.

Utilization Issues

Although CBCT appears to hold promise for advances in research and clinical orthodontics, there is some uncertainty and controversy related to its radiation dose, direct patient benefit and professional guidelines for use. In consideration of a fundamental concept of diagnostic imaging known as the As Low As Reasonably Achievable principle, a clinician has the responsibility of determining if the risks from diagnostic imaging outweigh the benefits of its use in patient care, which suggests that clinicians also must consider the potential harm to the patient if the imaging is inadequate and if a diagnosis or a problem is missed. In addition, imaging should be performed with a valid diagnostic goal.

Orthodontics involves the use of various radiographic modalities in its diagnostic protocols, ranging from panoramic radiographs and lateral cephalograms to complete series of radiographs. Although studies of radiation dosimetry are not directly comparable,[24] the exposure from CBCT is within the same range as traditional dental imaging.[25] The combination of traditional dental radiographs, particularly in a complete series, can result in a radiation dose that is substantially higher than that of CBCT.[26]

With respect to the topic of patient benefit, several articles describe the application of and rationale for using CBCT, as well as specific measures or diagnostic functions that are possible or improved with 3-D imaging.

Specific measures and functions of CBCT in clinical activities include more accurate assessment of lower incisor position[27]; measures of root length and marginal bone level[28]; management of impacted canines[29],[30],[31],[32]; visualization of upper airways,[33] including a report of substantial incidental findings of airway abnormalities in orthodontic patients[14]; evaluation of bone dehiscence and fenestration[34]; and anomalous mandibular premolars.[35] The therapeutic benefits of CBCT include measurement of the dentition[9] and tooth volume,[36] planning and evaluation of temporary anchorage devices,[20],[36],[37],[38],[39] monitoring of alveolar bone density and height in interdisciplinary periodontal and orthodontic treatment,[40] 3-D treatment simulation[41] and use in appliance manufacturing.[42] Most of these activities can be performed in one imaging session with a radiation dose that is in the same range as that of conventional images, which do not provide the same amount of data.

The British orthodontic society (BOS) published a set of radiographic guidelines[43] written specifically for dentistry. There have been three revisions in these guidelines and the recent update included the following points.[44],[45] They state that there are NO orthodontic indications for the following:

- Radiographs taken routinely for all orthodontic patients
- Full mouth periapical views before treatment
- A single lateral cephalometric radiograph for the prediction of facial growth
- Radiographs of the hand and wrist to predict the onset of the pubertal growth spurt
- Routine radiographs to investigate TMJ pain dysfunction
- Prospective radiographs for medico legal reasons
- Radiographs after treatment purely for professional examinations or for clinical presentations
- CBCT taken routinely for all orthodontic patients

The BOS advocates that the clinicians should note the following

- A radiograph should be taken only after a clinical examination and when it is deemed to provide a sufficient benefit to the exposed patient
- All radiographs should be clinically evaluated and results recorded
- There is no known safe level of radiation exposure
- Generally the benefits of diagnostic radiology outweigh the risks
- The level of risk is justified only when the patient receives a commensurate health benefit from a minimum dose.

The above guidelines may appear very strict. In practice, it would be impossible to determine if a patient is routine without conducting a comprehensive evaluation. Rather, a more practicable guideline would be that CBCT is indicated for comprehensive orthodontic treatment for which precise knowledge of the dentition; dentoalveolar volume; root morphology; possible supernumerary, impacted or ankylosed teeth and other dental abnormalities; temporomandibular joints; airways; and skeletal structures is necessary to understand completely the cause of the malocclusion, diagnosis, treatment planning and specific biomechanical therapy in the management of the patient's condition.

Conclusion

CBCT offers a lot of advantages for imaging in orthodontics. As a result, CBCT is being adopted more often. The clinical value proposition of CBCT is that it can describe craniofacial anatomy accurately and provide comprehensive information regarding anatomical relationships and individual patient findings for improved diagnosis, treatment planning and prognostication. Research and development of future applications of CBCT, such as simulation, growth prediction, forensics, modeling and manufacturing, is ongoing. It is the belief of the authors that with the introduction of CBCT in orthodontics overuse of this new technique is eminent. We strongly urge our colleagues to carefully go through their cases and refer patients for CBCT only when actually required.

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