Cone-beam Computed Tomography in Orthodontics Treatment Planning: A Review

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Abstract

Radiographic imaging is an important diagnostic adjunct in the assessment of skeletal and dental relationship for the orthodontic patient. Cephalometric analysis is performed to determine deviations in the skeletal and dentoalveolar relationship by identifying specific landmarks on both hard and soft tissues to consecutively calculate the spatial and angular relationship between them. Three-dimensional (3D) imaging techniques are becoming increasingly popular and have opened new possibilities for orthodontic diagnosis and treatment assessment. Recently, cone-beam computed tomography (CBCT) have been developed specifically for the maxillofacial region and it has many applications. The clinical value of CBCT is to describe craniofacial anatomy accurately and provide comprehensive information regarding anatomical relationship and individual patient findings for improved diagnosis, treatment planning and prognosis determination. Maxillofacial applications of CBCT have been used for patients that need maxillofacial surgery and patients with impacted teeth or any kinds of asymmetry but the lack of 3D standard population norms have restricted CBCT from routine orthodontic use. This article focuses on various contemporary and future applications of CBCT technology in orthodontics.

Keywords: Cone-beam computed tomography, Orthodontic diagnosis, Three-dimensional imaging technology.

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Introduction

Comprehensive visualization and record of the craniofacial complex have always been important goals in orthodontic imaging. These goals are achieved routinely by means of plaster models, photographs and radiographs. The current imaging techniques in the dental office are actually two-dimensional (2D) representation of three-dimensional (3D) subjects. These 2D projections have several disadvantages like magnification, distortion, superimposition and misrepresentation of structures.[1] Cone-beam computed tomography (CBCT) is a new diagnostic tool that has revolutionized diagnosis and treatment planning in the dental field by providing 3D representation of 3D object. Cone-beam computed tomography presents as a separate cone-beam adaptation of computed tomography (CT) imaging. An early volumetric CT predecessor of CBCT, the dynamic spatial reconstructor, was developed in the late 1970s by the Biodynamics Research Unit at the Mayo Clinic (Rochester, MN, USA). Initial interest was focused primarily on applications in angiography in which softtissue resolution could be sacrificed in favor of high temporal- and spatial-resolving capabilities.[2] Though 3D CT has been available to the medical profession for over 30 years now, its use in orthodontics has been restricted due to the high radiation exposure and the high cost of this technology. However, recent advances in CBCT technology have lead to dramatic decrease in radiation as well as in cost, making it a practical and attractive alternative to traditional imaging. The new CBCT machines can perform a full scan of the head in a few seconds and give the patient an effective dose of only 50 micro-Sieverts, compared with about 2000 from a conventional CT scan of the whole head.[3] This follows the as low as reasonably acceptable (ALARA) principle for radiation. Radiation concerns are further reduced when one analyze that a single CBCT scan can replace a number of conventional radiographs that are now considered essential for almost every orthodontic procedure. Thus, the routine use of CBCT scans for orthodontic diagnosis may not be very far away.[4]

Applications of Cbct in Dentistry

Cone-beam computed tomography was initially introduced for its role in the field of dental implantology. Currently, the utility of CBCT includes field of dental implantology, oral surgery, orthodontics, endodontics, sleep apnea, temporomandibular joint (TMJ) disorders, and periodontics, and it is expanding its horizon in the field of ear, nose and throat (ENT) medicine.[5]

Applications of Cbct in Orthodontics Treatment Planning

Lateral cephalograms & orthopantomogram (OPG) together with facial photographs are currently the main diagnostic imaging modalities used in the assessment of orthodontic problems. However, the use of 2D views in the analysis of 3D objects can cause overlapping of structures and lead to errors in landmark identification which has in turn led to a search for new techniques.[6] In contrast to conventional cephalograms, the errors due to malposition of the patient during image acquisition could be corrected in CBCT by slight adjustment. The first issue might be because errors of projection present in the conventional cephalograms and, therefore, the identification of landmarks of bilateral structures (e.g. the mandibular line) presents some inaccuracy.[7] Incorrect head posture during cephalometric radiography may produce right-left inaccuracies and leads to these Measurement differences. Cone-beam computed tomography cephalometric image reconstruction can be recommended as an alternative to conventional cephalograms when a CBCT volume is already available, thus, reducing the need for additional X-ray exposure and expense, since we can select the best orientation of the skull before generating CBCT-synthesized cephalograms, CBCT-generated cephalograms could be more reliable than conventional lateral cephalogram.[8]

Impacted Canine

Permanent maxillary canines are the second most frequent impacted teeth after third molar with 2% prevalence rate in the general population. Canines play an important functional and esthetical role in face.[9] Moreover, orthodontics have emphasized the importance of preserving impacted maxillary canines and introduced various effective techniques for the treatment of this condition. Therefore, it is imperative to locate and categorize impacted canines accurately for their optimal management. Localization of an impacted tooth necessitates an accurate investigation of the adjacent anatomical structures. Contacts between impacted tooth and adjacent teeth roots may have resorptive impacts on the impacted tooth. Precise detection of an impacted maxillary canine is the first step of management. Early detection of impacted maxillary canines could reduce the time, complexity and cost of the treatment as well as its complications.[10] Conventional 2D radiographic imaging was the most common imaging modality for the diagnosis of impacted maxillary canines as well as treatment planning. Besides, panoramic radiography is widely accepted as a standard in orthodontics for the preoperative diagnosis of such cases. However, some weaknesses, such as distortion projection errors, blurred images, and complex maxillofacial structures projected onto a 2D plane could reduce the accuracy and validity of 2D panoramic radiographs and increase the risk of misinterpretation.[11] Cone-bean computed tomography is a new imaging technique that recently became increasingly important in treatment planning and diagnosis in dentistry. This technique offers undistorted 3D images of patients' teeth without exposing them to high dosages of radiation comparing to conventional CT scan. Unlike panoramic radiographies CBCT does not distort the images of the impacted teeth.[12]

Orthodontic Mini-implants

The use of orthodontic mini-implants as an absolute anchorage device has seen a marked increase in orthodontic treatment. Despite their advantages over the extraoral anchorage methods, mini-implants can occasionally get loosen during treatment and fail to provide firm anchorage. A study showed that the rates of mini-implant failure vary between 11 and 30%.[15] The two major factors that clinicians should consider for mini-implant placement are safety and stability. Safety is avoiding root damage during implant placement in the inter-radicular space. Stability which plays a major role in preventing premature loosening of mini-implants, is obtained by placing the mini-implants in the alveolar bone with sufficient quantity and quality.[16] Fayed et al suggested that the optimal sites for miniimplant placement are between the second premolar and first molar and between the first and second molars at the buccal aspect of the posterior region of both jaws. In order to have adequate utility in clinical practice successful placement of mini-implants at the desired site is important.[17] Kim et al presented a surgical guide system that used CBCT images to replicate the dental models. For the purpose of proper positioning of orthodontic mini-implants, surgical guides were fabricated on these replicas and used for precise placement. Liu et al introduced a computer-added design/computer-added manufacturing (CAD/CAM) template with preoperative simulation for orthodontic miniscrew placement. Similarly, other authors have reported the extensive use of 3D planning with the help of surgical guides, stents, and templates for accurate mini-implant positioning.[18]

Cleft Lip & Palate

Bilateral complete cleft lip and palate (BCLP) represents the most severe manifestation of cleft lip and palate and accounts for 12.2% of all orofacial clefting. The rehabilitation protocol for BCLP includes lip and palate repair at 3 and 12 months of age. The first orthodontic intervention is performed during the late mixed dentition in order to correct posterior and anterior crossbite before secondary alveolar bone graft (SABG) surgery. During this phase of treatment, tooth movements in the cleft area must be performed with care considering the thin alveolar bone plate.[19] Buccal and mesiodistal dental movements as well as rotation of teeth adjacent to the cleft could cause periodontal injuries, such as bone dehiscences and fenestration, affecting SABG results. Teeth adjacent to a cleft display higher prevalence of gingival recession compared to the same teeth in noncleft patients.[20] Orthodontic tooth movement toward the cortical bone plate can also lead to bone dehiscences, contributing to the development of gingival recession in the longterm.[21] Although there is enough clinical evidence of mucogingival problems and decreased crestal bone levels in the cleft region, no previous study has reported the 3D morphology of periodontal alveolar bone surrounding teeth in this area. This information cannot be obtained from the conventional radiographs.[22] Therefore, the need to explain the periodontal consequences of tooth movement in the premaxillary region before SABG has led to the use of CBCT. This type of diagnostic imaging allows reproduction of a real maxillary section in any plane, demonstrating all the anatomical structures in depth. With CBCT, individualized bone plate images can be observed and analyzed, allowing a quantitative evaluation of these regions.[23]

Apical Root Resorption

External apical root resorption is a common undesirable side effect of orthodontic treatment. The clinical diagnosis is based mainly on routine radiographic procedures, such as panoramic OPG and periapical radiography. However, some root shortening is required before it is detectable on the radiograph.[13] Furthermore, OPG has been shown to overestimate the amount of tooth loss by 20% or more compared with periapical radiography, and digitized periapical radiographs have been shown to underestimate apical root resorption compared with a microcomputed tomography scanner. Cone-beam computed tomography is a powerful tool to show apical root resorption during orthodontic treatment, whereas OPG underestimates it. Root resorption is a 3D phenomenon, and its extent must be quantified with precision.[14] Cone-beam computed tomography provides highly detailed 3D imaging with only one X-ray exposure of approximately 18 seconds. Imaging can be obtained at any angle, thus, it offers optimum viewing and help in eliminating superimpositions. The diagnostic ability of CBCT to detect simulated external root resorption was studied by Rossini G et al. Cavities of different depths and diameters were prepared on the cervical, middle, and apical thirds of the buccal surfaces. The evaluation of the CBCT's diagnostic ability showed high sensitivity and excellent specificity.[10]

Root Fractures

The clinical presentation and radiographic appearance of a vertical root fracture (VRF) frequently create a diagnostic problem for the clinician. Lack of correct Diagnosis often leads to unnecessary invasive surgery and/or extraction of the tooth. The ability to clinically detect VRF is currently limited to the use of conventional radiography.[24] This technique has limitations of 2D nature and inability to reveal longitudinal fractures which traverse in any direction not parallel to the X-ray beam. Furthermore, superimposition of other structures limits the facility for detection of these fractures. The CBCT produces 3D images with smaller patient radiation dose. The advancement and utilization of CBCT technology has become increasingly popular. Axial slices are found to be more accurate than sagittal and coronal slices for detecting VRF.[25]

Rapid Palatal Expansion & Alveolar Bone Thickness

Thickness of the alveolar bone is important to orthodontists who use rapid palatal expansion to increase the transverse dimension of the maxilla. Most rapid palatal expansion devices are tooth-bone and produce different degrees of skeletal expansion and dental tipping. This depends upon the age of the patient at the time of treatment. Generally, it has been found that in young patients midpalatal suture is more patent due to which they have greater skeletal expansion than older patients in whom the suture get fused.[26] As a result, older patients have greater dental tipping during rapid palatal expansion. There may be adverse effect on the supporting alveolar bone. Cone-beam computed tomography images provide an invaluable information for evaluating this effect. While all studies on rapid palatal expansion treatment demonstrated both dental and alveolar tipping, none of them emphasized on the detrimental effects (such as dehiscences or fenestrations) to the alveolar bone supporting the posterior teeth. Cone-beam computed tomography images are clear enough to measure alveolar bone thickness to an accuracy of 0.6 mm. In fact, one recent study suggested that CBCT images with a voxel size of 0.4 mm actually overestimate alveolar bone loss following rapid palatal expansion.[27]

Unsuspected Pathologies

It is very important that clinicians examine all radiographic images for pathology. Cone-beam computed tomography generates highly detailed images which are helpful in localizing unsuspected pathology. The orthodontics literature has several case reports supporting this fact. The rates of incidental findings on CBCT images taken of orthodontics patients are now being published.28 The overall rate of incidental findings on CBCT images is 24.6%, with airway (21.4%), TMJ (5.6%) and endodontic (2.3%) pathology among the most common in orthodontics patients. In a separate study, unexpected maxillary sinus pathology appeared on 46.8% of CBCT images of orthodontics patients.[29]

Airway Analysis

Evaluation of upper airway space is a routine procedure in orthodontic diagnosis and treatment planning. Lateral cephalometric radiographs have been used routinely to assess airway space permeability. However, their use is limited because they provide 2D information of 3D structures. By producing 3D images, CBCT allows professionals to accurately determine the most constricted area, where greater resistance to air passage occurs.[32] Software is available for assessment of the upper airway space, such as in vivo Dental, 3dMD vultus and Dolphin Imaging. Dolphin Imaging program version 11.0 is an airway space analysis tool that not only enables the evaluation of the shape and contour of the upper airway space in 3D, but also calculates volume, sagittal area and the smallest predefined cross-sectional area in the airway space. To assess images in the program, one must first import the files in DICOM single-file format from CBCT images. Once imported, the 3D image of the patient's head must be oriented in the virtual space in like manner as in the cephalostat.[33]

TMJ Assessment

Although magnetic resonance imaging remains the gold standard for imaging the intra-articular components of the TMJ, evaluation of the bony components is still dependent on conventional panoramic radiographs. Panoramic radiographs can provide a general impression of the joint in 2D but are less effective in evaluating changes in the condyle and the temporal components of the joint.[34] The images provided by current CBCT machines have been shown to provide a complete radiographic evaluation of the bony components of the TMJ. The resulting images are of high diagnostic quality. Since, the radiation dose and cost is markedly lower compared with conventional CT, CBCT may soon become the investigation of choice for evaluating bony changes of the TMJ.[35]

Dental Arch Analysis

Nowadays, there have been replacement of hard copy with digital records in clinical practice. So, orthodontists have started using digital casts for diagnosis and treatment planning. There are currently two approaches to generate digital casts that involve CBCT. In first approach CBCT is used to scan impressions of the patient's teeth to generate a digital model.[30] The second approach do not use the impression rather they use CBCT of the patient's teeth. A preliminary study showed that a medium field sensor with the patient in an open mouth position and an image with an anisotropic voxel size of 0.4 × 0.6 mm produce the optimal CBCT image of the dental arches. Cone-beam computed tomography scans of alginate and vinylpolysiloxane impressions of a typodont are accurate for measuring intra-arch parameters (arch perimeter, arch width), but are not suitable for measuring interarch occlusal relationships.[31]

Orthognathic Surgeries

Quantitative and qualitative analysis of skeletal displacement, adaptive response and resorption that could not be attempted with 2D techniques can now be carried out through 3D CBCT reconstructions. The complex movements during surgery for dentofacial deformities need to be assessed in 3D to improve result and reduce symptoms of TMJ disorder after surgery. In order to analyze changes in the subject, images of different phases are superimposed with the software named Imagine in a fully automated method.[32] Since the cranial base is not changed by the surgery, its surfaces are used in the registration procedure, where the software compares the gray level intensity of each voxel between two CT images. In this way, the cranial base of the presurgery CT is used as reference for comparison. The presented 3D superimposition method allows the assessment of important structural displacements following surgery and its stability.[36]

CBCT in Pediatric Patients

The major advantage of cbct in pediatric patients arises from lessor scan time and lessor complicated apparatus which reduces the anxiety in childrens. A major advantage of cbct in comparison to conventional ct is reduced doses. Clinical applications in pediatric patient is development of teeth as conventional imaging makes it difficult to visualize the complex phenomenon of tooth development, other includes caries diagnosis, craniofacial morphology, soft tissue analysis, cleft lip, cleft palate and airway analysis. However use of cbct in children should be justified depending upon the case such that its applications outweighs the potential risk of radiation exposure.

Conclusion

Over the past decade since the introduction of CBCT into dentistry, several studies have accumulated valuable data on technology assessment, craniofacial morphology in health and disease, treatment outcomes and efficacy of CBCT images in diagnosis and treatment planning. Cone-beam computed tomography offers advantages for imaging in orthodontics. As a result, CBCT is being adopted in many dental practices. 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 prognosis. Research and development of future applications of CBCT, such as simulation, growth prediction, forensics, modeling and manufacturing, is ongoing.

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