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Special Article
บทความพิเศษ

3-Dimensional radiographic analysis for orthodontics

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Abstract

This is a first of a kind attempt at a comprehensive three-dimensional orthodontic analysis based on Cone Beam CT data. It includes elements that are based in traditional orthodontic analyses which draws upon existing knowledge base, and it also includes novel approaches to the examination of volumetric 3-D perspective. The goal of this analysis is to extract pertinent details from the image volume and provide the orthodontist with clinical applications of this information. The orthodontist will then be able to better assess the patient's malocclusion condition and develop enhanced diagnosis and treatment approaches.

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Key words: *Cone Beam CT; orthodontic; three-dimensional*

Introduction

The introduction of three-dimensional (3-D) radiographic imaging in dentistry, by way of Cone Beam Computed Tomography (CBCT), has led to a multitude of clinical applications across all dental disciplines. Access to CBCT imaging services is increasing at a near exponential rate since the first device was first introduced to the United States in 2000. The advantages of 3-D imaging are numerous,[1] and studies on the effective absorbed dose show that radiation exposure is much lower than medical CT imaging and more within the range of other dental film series.[2,3] In orthodontics, we are just beginning to establish the potential diagnostic and therapeutic application of 3-D imaging.[4]

We are at the crossroads of traditional dental imaging and our existing knowledge base, which is primarily based on two dimensional records. Yet we know that 3-D imaging can offer valuable information about our patients leading to a more extensive evaluation and improved diagnosis and treatment planning. With this in mind, we describe a comprehensive analysis of the CBCT volume for orthodontic diagnosis and treatment planning. This analysis contains elements that are grounded in our traditional orthodontic workup, but it also contains elements and improvements that are made possible only with three-dimensional imaging and software tools. The analysis provides both diagnostic and therapeutic information. The individual components of the analysis are described below.

I. Lateral and Frontal Cephalometric Views

Fig. 1 (a) Frontal cephalogram (b) Lateral cephalogram (c) Lateral cephalogram and tracing (d) Tracing

A fundamental basis of 3-D imaging is that the resultant volume can be reformatted to provide infinite perspectives or viewpoints. Frontal cephalograms (Fig. 1a) and lateral cephalograms (Fig. 1b) can be created and subsequently imported into any cephalometric analysis program for digital tracing (Figs. 1c and 1d) and measuring values.

Lateral Cephalogram (LC):

Although the CBCT generated LC may appear similar to conventional LC, there are several distinct advantages that the CBCT technique presents which enhances the visualization process. Conventional LC is derived from a technique called perspective projection, and the geometric result is an inherent magnification of the image depending on the distance of the structure to the film (e.g. left versus right mandibular body). This often results in the double lower border of the mandible that we often see in conventional LCs. Even if the left and right porions were correctly lined up and the head was in perfect position, we would still not be able to determine whether the double structure is caused by a true skeletal asymmetry or a radiographic artifact. With CBCT LCs, this projectional magnification is computationally corrected during the primary reconstruction process to create an orthogonal image. With a standard of known length placed in the field of view, this CBCT LC can be calibrated to a true 1:1 ratio representation of the structure being imaged.

Frontal Cephalogram (FC):

Similar to the lateral cephalometric view, the frontal cephalometric view is created using software tools. A distinct advantage of CBCT generated frontal cephalograms is that the software is able to excise extraneous cervical spine and parts of the occiput data

thereby eliminating the superimposition of irrelevant structures. The resultant CBCT derived FCs provide remarkably clear images of pertinent maxillofacial structures and establishes a more reflective representation of true cranial relationships.

We recognize that many groups in the world are developing 3-D cephalometric analyses and when this information becomes more complete, it will be a desirable component of the analysis. Certainly these are welcome advances and will greatly augment the comprehensive analysis of patients; however, at the present time much of the orthodontic background and clinical approaches are still based on the lateral and frontal cephalometric views.

II. 3-D Skeletal Views

The volumetric 3-D skeletal view is a novel way to visualize the relationships of maxillomandibular structures to the cranial base (Figs. 2a, 2b, 2c, 2d, 2e). These views allow for surface inspection of osseous morphology of the jaws. A key area to examine is the alveolar bone height. This is particularly relevant in adults and periodontally compromised patients. Surface irregularities due to ectopic teeth, bone dehisciences, salivary gland invaginations and other abnormalites can be visualized. Occasionally these surface irregularities extend deep into the alveolar bone between the roots of teeth. Knowledge of these conditions allows the orthodontist to plan accordingly.

Fig. 2 (a) Right buccal profile (b) Right buccal oblique (c) Frontal (d) Left buccal oblique (e) Left buccal profile

*** Note that in Figs. 2b, 2c, and 2d the spinal column was excised so as not to create unnecessary superimpositions of overlapping structures. This excised information is still retained within the volumetric data and can be recalled at any point in time.

Lingual Views:

An entirely new method of occlusal assessment facilitating orthodontic diagnosis is the lingual view, as if the clinician was looking from the back of the patient's head into the oral cavity (Figs. 2f, 2g, 2h, 2i). This is made possible only with recent enhancements in CBCT software features.

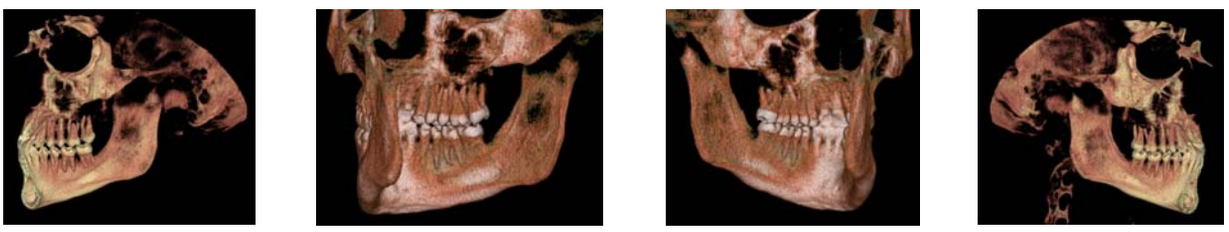


Fig. 2 (f) Right lingual profile (g) Right lingual oblique (h) Left lingual oblique (i) Left lingual profile

III. Facial Analysis

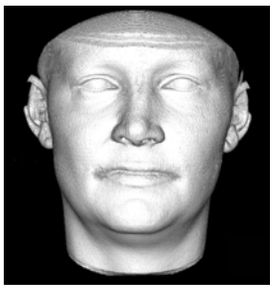
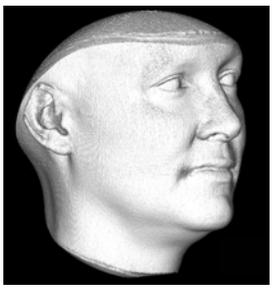
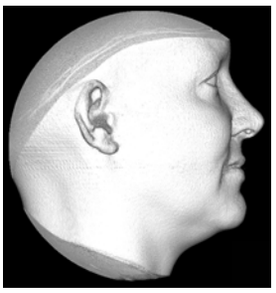
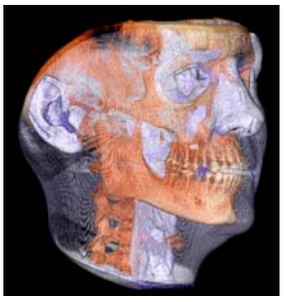
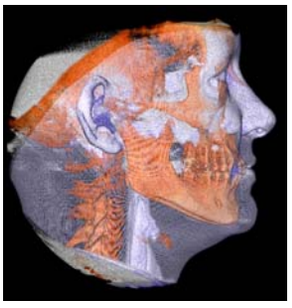




Fig. 3 (a) Frontal (b) User-defined (c) Lateral

Standard photography for facial analysis is a simple 2-dimensional representation of facial features and are not registered to the underlying supporting skeleton. The 3-D volume allows for frontal, lateral and any user-defined view of the face (Figs. 3a, 3b, 3c). By changing the translucency of the image, one can determine specifically, where the soft tissues are relative to the skeleton. This has tremendous implications for planning of tooth movements and/or orthognathic surgery or other treatments that could alter facial appearance (Figs. 3d and 3e).



(d) Superimposed soft tissue on skeletal structures [user-defined projection]



(e) Superimposed soft tissue on skeletal structures [lateral projection]

IV. Alveolar Ridge Shape and Volume

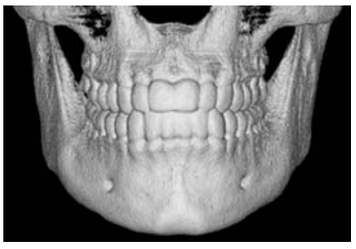
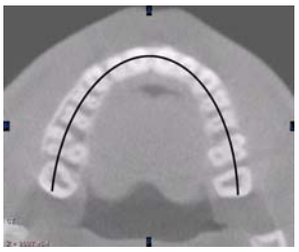
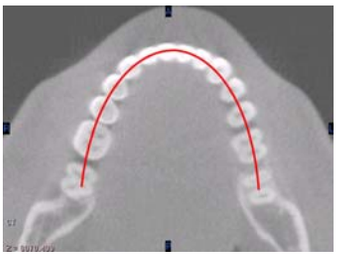
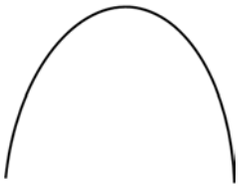




Fig. 4 (a) Frontal (b) Maxillary axial trace (c) Mandibular axial trace



(d) Maxillary archform

(e) Mandibular archform

(f) Maxillary and mandibular archform co-ordination

Assessment of alveolar ridge shape and volume is important for orthodontic diagnosis and treatment planning. The frontal view of the maxillary and mandibular arches (Fig. 4a) enables a clinician to assess vertical and transverse dimensions as well as volume and can be used to evaluate arch to arch discrepancies and vertical limits of tooth movement. In addition the frontal view is correlated with the TMJ views presented in the next section. This allows for the clinician to assess temporomandibular joint positions relative to the intercuspal positions shown. The occlusal views of the arches reveal relative tooth positions within the arches and defines the shape of the alveolar bone support (Figs 4b and 4c). Tracings can be made in both the maxillary and mandibular arches to reveal arch forms (Figs. 4d and 4e). The tracing is typically made at the height of the alveolus, but can be made elsewhere depending on user preferences. The arch forms can then be superimposed to reveal discrepancies and/or compatibility (Fig. 4f). Moreover, the arch forms can be printed lifesize to allow for selection or fabrication of orthodontic archwires for the patient. Future developments to this component of the analysis are underway to have the ability to conduct arch length measurements and Bolton analysis from the dental images.

V. 3-D Review of the Dentition

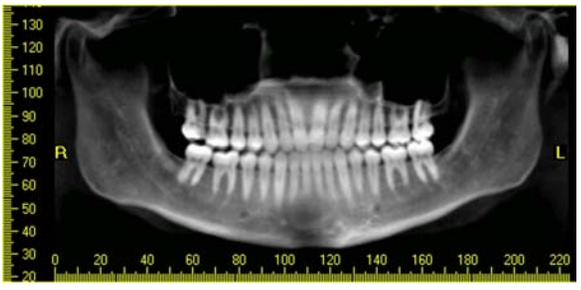
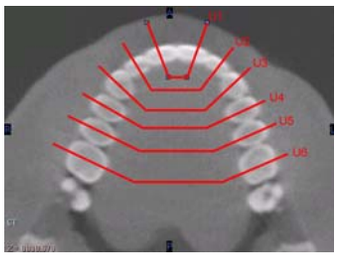
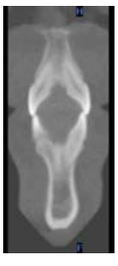


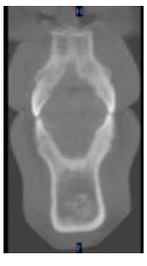
Fig. 5 (a) Panoramic (Note - no distortion and superimpositions)



(b) Tooth pairs maxillary (Mx) occlusal index



(c) U1 (Mx central incisors)



(d) U2 (Mx lateral incisors)

(e) U3 (Mx canines)

(f) U4 (Mx 1st premolars)

(g) U5 (Mx 2nd premolars

(h) U6 (Mx 1st molars)

V. 3-D Review of the Dentition (continued)

Fig. 5 (i) Right dentition (j) Frontal dentition (k) Left dentition

*** Noteworthy for this patient scan is that the maxillary and mandibular first molars have cemented metal bands. Unlike conventional radiographs, the 3-D reconstruction has minimal starburst-like artifacts often associated with imaging metal objects.

The three-dimensional review of the dentition includes a panoramic view (Fig. 5a), left and right side tooth pairs (Figs. 5b, 5c, 5d, 5e, 5f, 5g, 5h), and 3-D views of the dentition. The panoramic view is very similar to a traditional panoramic dental view however it is remarkably clear since there is no superimposition of the spinal column and contralateral side. In addition, it does not contain the projection artifacts of traditional panoramics such as the burnout area often observed in the anterior incisor areas. The left and right side tooth pairs are used to assess for asymmetries as well as identifying the position of the roots in relation to the buccal and palatal/lingual cortical plates of the alveolar bone support. Some patients have alarmingly thin alveolar bone around their tooth roots. This condition would not be seen using traditional orthodontic records. Prior knowledge of this condition allows the orthodontist to make better treatment decisions and/or seek interdisciplinary collaborations. The 3-D views of the dentition are reminiscent of textbook images describing dental development (Figs. 5i, 5j, 5k). These views allow for rapid and efficient evaluation of the dentition, particularly during the mixed dentition phase. In the developing dentition, these projections illustrate erupted and erupting teeth, as well as developing teeth, their relative positions and overall formation for root structures. The three-dimensional nature of these views allows for precise localization of all the teeth in the dental arches, thereby facilitating the management of tooth eruption and possibly leading to earlier intervention of potentially emerging problems.

VI. Temporomandibular Joints

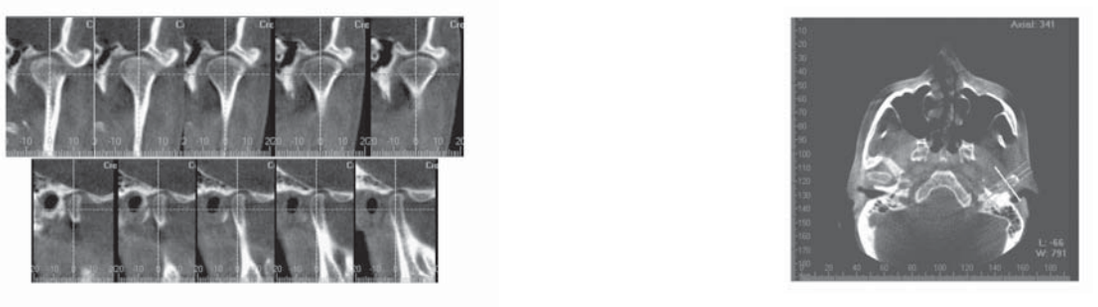


Fig. 6 (a) Coronal and sagittal sections (b) Axial view

Both coronal and sagittal sections of the temporo-mandibular joints (Fig. 6a) are included in the 3-D orthodontic analysis. Axial views (Fig. 6b) are also shown to help orient the coronal and sagittal sections. Since these images are produced from one volume these joint views are correlated with the occlusal views. Functional shifting can occasionally be detected as differences in the left and right joint views.

VII. Sinuses and Airway

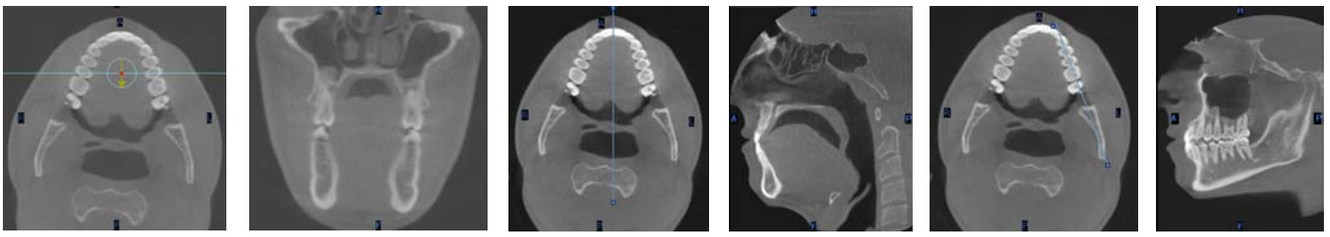


Fig. 7 (a) and (b) Coronal views (c) and (d) Sagittal views (e) and (f) Oblique views

The last component of the 3-D orthodontic analysis is a review of the sinuses and airway. Selected coronal (Figs. 7a and 7b), sagittal (Figs. 7c and 7d), and oblique (Figs 7e and 7f) views are included to show the air spaces. We feel this component of the analysis is particularly relevant to orthodontics since mouth breathing and airway obstruction are considered a prime etiology of malocclusion. Indeed, a review of 500 patients imaged by Cone Beam CT shows that approximately 25% have significant airway findings. Furthermore, airway patency or obstruction often influences significantly the decision to pursue orthodontic and orthognathic treatments as the primary choice.

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การวิเคราะห์ภาพรังสีแบบสามมิติสำหรับงานทันตกรรมจัดฟัน

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บทคัดย่อ

บทความนี้บรรยายถึงความพยายามในการวิเคราะห์ทางทันตกรรมจัดฟันในสามมิติแบบบูรณาการ โดยใช้ข้อมูลจากโคนบีมซีที การวิเคราะห์นี้ประกอบด้วย ส่วนที่ได้จากการวิเคราะห์ทางทันตกรรมจัดฟันแบบดั้งเดิมซึ่งอาศัยความรู้พื้นฐานที่มีอยู่แล้ว และยังรวมถึงการตรวจแบบทันสมัยด้วยวิธีการสามมิติเชิงปริมาตร เป้าหมายของการวิเคราะห์นี้คือ การดึงรายละเอียดที่เกี่ยวข้องจากปริมาตรในภาพ ทำให้ทันตแพทย์จัดฟันสามารถนำข้อมูลเหล่านี้ไปใช้ทางคลินิกได้ โดยทันตแพทย์จัดฟันสามารถประเมินภาวะการสบฟันที่ผิดปกติของผู้ป่วยได้ดีขึ้น และนำไปสู่การวินิจฉัยและการรักษาที่ดีขึ้นด้วย

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คำสำคัญ: *โคนบีมซีที; ทันตกรรมจัดฟัน; สามมิติ*