University of Alberta

# A Comparative Analysis of Angular Cephalometric Values between CBCT Generated Lateral Cephalographs versus Digitized Conventional Lateral Cephalographs

by

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## Dedication

This work is dedicated to my wife, Kalyani and boys, Neelan and Jayan, for their support and patience. Although my world has grown in leaps and bounds, it continues to revolve around you all. With much love and thanks.

## ABSTRACT

**OBJECTIVES:** 1) To determine precision of angular measurements in both the 2D and 3D imaging systems, and to 2) to ascertain the difference in cephalometric values between traditional and CBCT generated cephalographs.

**METHODS:** Traditional cephalograms (Orthoceph OC100) and volumetric CBCT imaging (Newtom 3G) were performed on 36 patients from the incoming pool of treatable cases at the University of Alberta Graduate Orthodontic Clinic, Edmonton. Lateral cephalometric analysis using Dolphin 3D was performed and ten angular measurements were evaluated. Inter-rater and Intra-rater reliability was assessed using inter-rater correlation coefficient (ICC). Paired MANOVA was used to compare differences in measurements between the two image modalities.

**RESULTS:** High inter-rater reproducibility (ICC>0.8) with all angles was demonstrated in both imaging modalities. Only SN-FH (Conventional 95% CI: 0.584-0.965; CBCT 95% CI: 0.584-0.950) demonstrated significant difference between raters. No significant difference in the angular measurements was detected between the two image modalities ($p>0.1$ for all measurements, $\alpha=0.05$).

**CONCLUSIONS:** A lateral, full thickness x-ray construction from CBCT imaging (NewTom 3G) can be used to perform traditional cephalometric analysis with comparable levels of precision and accuracy.

## Acknowledgements

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## INTRODUCTION & LITERATURE REVIEW

## 1.1 INTRODUCTION

The treatment planning process in the field of orthodontics involves the acquisition of a reservoir of information, from which the orthodontist can formulate a diagnosis and devise an appropriate, individualized treatment plan. Of the various tools used by the orthodontist, the lateral radiograph of the head has become an accepted standard for diagnosis by way of cephalometric analysis. Cephalometric analysis involves defining skeletal and soft tissue landmarks on the lateral head image and obtaining linear and angular measurements between these landmarks (1). The information gathered from cephalometric analysis can provide valuable information to the orthodontist in assessing the patient's skeletal and dental classification, understanding and predicting the growth pattern of the individual, and evaluating the treatment outcome.

Despite the ubiquitous use of lateral cephalographs in orthodontics, inherent errors exist in the imaging process. Problems with magnification and projection error continue to affect the image quality, often making landmark identification of skeletal and soft tissue very difficult (1-5). Through the surfeit of technological progress, new and improved radiographic imaging is becoming available. Of the recent advancements in the tools for clinical diagnosis, the application of cone beam computed tomography (CBCT) is finding its way into the field of dentistry (6,7). Cone beam computed tomography avoids many of the projection problems found in conventional lateral cephalographs and offers the opportunity for the orthodontist to evaluate the craniofacial structures in greater detail and precision, while allowing three-dimensional (3D) access to the image (8).

Currently there are many CBCT imaging systems available in the market (9-12). With decreasing cost and radiation exposure of CBCT machines and the greater image resolution acquisition offered, there is an ever-increasing interest in the potential use of CBCT in orthodontic diagnosis and treatment planning. Despite the inherent radiographic errors, cephalometric analysis of lateral cephalograph images obtained from conventional radiography continues to be primary diagnostic protocol in orthodontic offices today. If the profession of orthodontics is to adopt CBCT technology as a replacement for conventional radiography, this transition will ultimately require a development of a standardized cephalometric analysis in three dimensions. Thus the identification of new landmarks and structures will have to be created and assessed for their clinical diagnostic value. However, before this can occur, a necessary first step will be to compare the diagnostic value of the cone beam CT to the conventional radiography with respect to established landmarks used in cephalometric analysis.

## 1.2 PROBLEM STATEMENT

Cephalometric analysis has been plagued with errors ever since it's adoption into the diagnostic process of orthodontics. In fact, the correction of measurement errors in cephalometrics has been a leading topic of discussion since Broadbent's introduction of the lateral cephalometric x-ray in "A New X-ray Technique and It's Application in Orthodontia" in 1931 (13). The source of the problem stems from the non-parallel nature of the x-rays used in dentistry. Traditional analogue, film-based cephalometric imaging utilizes a static fan shaped x-ray beam. When the image is taken by the x-ray source, magnification errors arise due to the divergent nature of the x-rays. Various strategies including the use of a beam collimator and increased x-ray to film distance have been employed, however, magnification problems continue to persist (1,5,13-15).

Since bilateral structures are being imaged from only one side of the head, overlapping structures can often lead to difficulty in discerning critical landmarks and structures. Furthermore, a disproportionate magnification occurs with the side closest to the x-ray source exhibiting greater magnification, contributing further to increased difficulty of landmark identification when the two sides are superimposed (Figure 1.1). As the definition of the skeletal landmarks is crucial in determining the patients' skeletal and dental malocclusion, growth pattern and treatment outcome, errors in landmark identification are considered the greatest sources of error in cephalometric analysis (16-19).

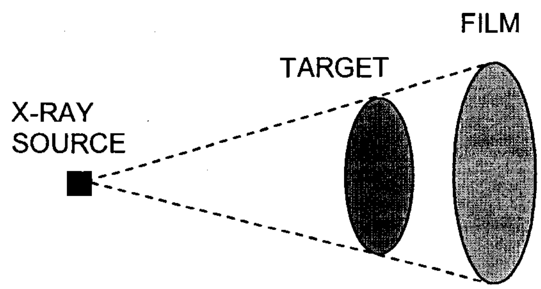



Figure 1.1 Magnification of image due to non-parallel x-rays

Another factor that can contribute to projection errors is the position of the patient's head during radiographic image acquisition (Figure 1.2). Studies have shown that head rotation can have a significant effect on the horizontal linear cephalometric measurements; however angular measurements did not appear to be significantly affected by magnification (16,20-22). With standardized methods

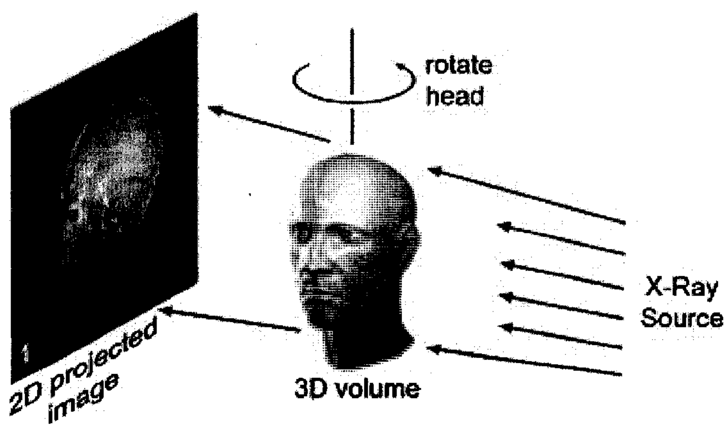



Figure 1.2 Rotation of head during lateral radiography (92).

of taking film-based lateral cephalographs, including predetermined x-ray to target to film distances, standard voltage and amperage settings, and nasal and ear rod devices to minimize head rotation, projection error caused by incorrect patient position is considered as part of the random errors in cephalometric analysis.

CBCT technology offers a resolution to the intrinsic problems of conventional radiography. Due to the high image acuity and the visualization of the skull in three dimensions, the clinical application of CBCT is becoming widespread in numerous fields of dentistry, including oral surgery and dental implantology (11,12,23-27). In orthodontics, facial and dental morphology is assessed by a geometric analysis of the lateral radiograph of the head. However, as stated earlier, there are sources of error involved in this process with analogue radiographic imaging devices. Recent studies have demonstrated that accurate multiplanar and three-dimensional images can be generated from a CBCT scan (6,11,28-31). Therefore the examination of radiographic information from clinically accurate images obtained from CBCT may offer a more valid diagnosis of the patient's dental, skeletal and growth patterns. However, before CBCT can be implemented in the orthodontic treatment planning process, the diagnostic soundness of CBCT must first be ascertained with respect to the current standard of conventional cephalometrics analysis (Appendix B, Figure 3 and 4).

## 1.3 RESEARCH QUESTIONS & STUDY OBJECTIVES

To ascertain the diagnostic validity of the CBCT in relation to traditional cephalometric analysis used in conventional lateral cephalographs, the research questions and study objectives for the thesis are proposed and outlined below.

Research Questions

1. Can cephalometric angular values be reliably measured on two-dimensional lateral cephalograph images synthesized from volumetric CBCT data?

2. Is there any difference between the diagnostic value of lateral cephalometric images obtained from conventional means versus CBCT?

Primary Objective:

- To determine the repeatability of angular cephalometric measurements between three time points (T1, T2 and T3) for respective conventional and CBCT images on a sample population

- To determine the reproducibility of angular cephalometric measurements between three raters (R1, R2 and R3) for respective conventional and CBCT images on a sample population

Second Objective

- To determine the difference between angular cephalometric measurements between the conventional and CBCT images from the same patient.

## 1.4 HYPOTHESES

Research Question 1

Reliability: Intra-rater

Null hypothesis:

- There is no difference in the angular cephalometric values between time points T1, T2 and T3 in the lateral cephalographs synthesized from CBCT

Alternate hypothesis:

- There is a difference in the angular cephalometric values between time points T1, T2 and T3 in the lateral cephalographs synthesized from CBCT

Reliability: Inter-rater

Null hypothesis:

- There is no difference in the angular cephalometric values between Raters: R1, R2 and R3 from the lateral cephalographs synthesized from CBCT

Alternate hypothesis:

- There is a difference in the angular cephalometric values between Raters: R1, R2 and R3 from the lateral cephalographs synthesized from CBCT

Research Question 2

Null hypothesis:

- There is no difference in the angular cephalometric values between images obtained from conventional radiography and CBCT on the same patient

Alternate hypothesis:

- There is a difference in cephalometric values between images obtained from conventional radiography and CBCT on the same patient

## 1.5 LITERATURE REVIEW

### 1.5.1 CEPHALOMETRIC ANALYSIS

Cephalometric analysis is an integral part the orthodontic diagnosis and treatment planning. The process involves taking a lateral radiograph of the head and defining skeletal landmarks on the acquired two-dimensional image. Conventionally the x-ray source is placed 5 feet from the head and the film is positioned 15 inches from the head (32). This is done to minimize the magnification of the target on to the film (1,13). The film image is obtained by conventional film exposure using the silver halide emulsion in x-ray films. The image is then hand traced and the skeletal and soft tissue landmarks are identified (See Appendix A). From these anatomical landmarks or points, both angular and linear measurements are taken. In the past, orthodontists have devised numerous geometric analyses in an attempt to interpret the cephalometric measurements into a meaningful standard by which the profession could classify dental and skeletal malocclusion, assess the growth of the face and to determine orthodontic treatment outcome. Today, cephalometric analysis continues to provide a guideline by which orthodontists govern their diagnosis and treatment plan.

### 1.5.2 CEPHALOMETRIC IMAGE QUALITY

#### 1.5.2.1 DENSITY AND CONTRAST

The quality of the image obtained is of utmost importance to cephalometric analysis. Errors in landmark identification due to inadequate image resolution and clarity can alter the cephalometric measurements and can ultimately affect the validity of the diagnostic information acquired. Unfortunately due to the nature of film-based radiography, many sources of error are incumbent in the process of acquiring the object image (17,19,33).

One of the features that can affect the image clarity and resolution is contrast and density of the film image. The density of the film is defined as the degree of darkness of the film and the contrast represents the difference in densities in between adjacent areas on the image. The density of the film is controlled by a host of factors including tube voltage (Kvp), tube current (mA), time of exposure, film speed, film processing and distance of the x-ray source to the target. Likewise the tube voltage and film processing can affect the contrast of the film (34-37). Because the head receives a uniform exposure of radiation during a lateral cephalograph, differing thicknesses at various points on the skull can affect the image obtained. Areas with more superimposed structures will be under-exposed, while areas in the front of the face will be over-exposed (38). Fortunately, ideal imaging conditions have been standardized with optimal settings with new x-ray devices, improved radiographic film processors and faster films. The advent of intensifying screens for film-based radiography and digital imaging plates have also played a major role in improving image quality, while reducing patient radiation exposure (39,40). Moreover, the digitizing process has allowed for the manipulation of radiographic images, thereby controlling the image quality and subsequent visualization of anatomic landmarks (34,41).

#### 1.5.2.2 PROJECTION ERROR

Like all transmission radiographs, lateral cephalometric x-rays interpret the three-dimensional structure into a two-dimensional plane. The resulting superimposition of anatomical structures complicates image interpretation and landmark identification. Moreover, structures closer to the x-ray source appear more magnified than those closer to the detector (Figure 1.3) (17,18,42). In lateral cephalometrics, the head is conventionally imaged from the right side, thus the right side is usually magnified more than the left. The situation becomes more difficult when the objective is to assess individuals with severe asymmetries (22,43-46). To compensate for magnification errors, basic mathematics for compensating for projection errors in cephalometry have been described (19).

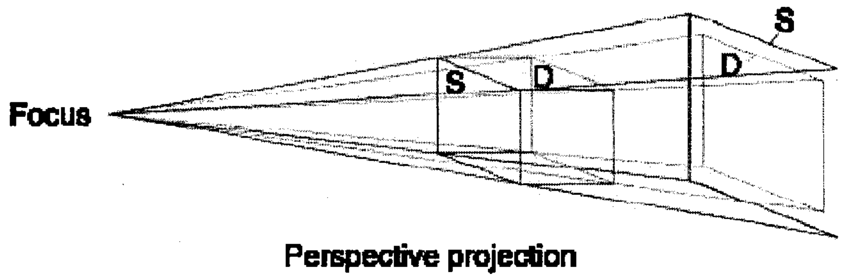



Figure 1.3. Disproportional magnification of object in the image (52)

Another source of projection error that should be considered is the incorrect position of the patient's head. The effect of head rotation on linear and angular measurements has been investigated in several studies. A study by Alqhvist et al, demonstrated that when the head position was altered by less than 5 degrees in the horizontal plane, the errors were less than 1 % in length measurements (mm) and less than 1 degree in angular distortion (18). In a study by Yoon et al, head rotation demonstrated little effect on angular measurements, while a maximum error of 5.78% was noted at 15 degrees of deviation along the z-axis (20). In general, linear measurements in the transverse direction were found to have slightly higher error than the vertical measurements with improper head position during radiographic imaging (17,18,22,47). Today, differences in magnification are rarely assessed in cephalometric studies because the method of image acquisition has become standardized.

### 1.5.3. LANDMARK IDENTIFICATION

The correct identification of craniofacial landmarks on the lateral cephalometric radiograph lays the foundation for cephalometric analysis, however the process is prone to significant variation. This is partly due to projection errors, variation in rater interpretation and radiographic technique (2,16,18,38,43,44,48). As certain anatomical structures are more identifiable than others, a systematic pattern of error prevails in landmark identification, with some points exhibiting higher precision among observers (49-51). In particular, Sella, Nasion and Pogonion tend to be less subject to error, whereas areas such as A point, Porion and Condylion tend to exhibit greater variation to identification (38,43,52) (See Appendix A for location of skeletal landmarks). Furthermore, dental landmarks tend to exhibit greater variability than skeletal anatomic points (53). Because all areas of the film are imaged with uniform exposure, the more dense regions of the skull where there is greater overlap of structures or greater bone density will have a tendency to be underexposed. Likewise, areas with relatively less bone density, such as the anterior part of the skull, will be over-exposed. Both of these situations can make identification of the cephalometric points difficult (1,13,54).

Due to the variability in the location of certain landmarks, cephalometric references based on landmarks that are not reliability identified are not recommended (43,48,52). Since variability of Porion and Orbitale (Frankfort Horizontal) is significant, a more identifiable reference, Sella to

Nasion, is recommended for cephalometric analysis (55-57). Although landmark variation exists, the effect on cephalometric measurements does not appear to be clinically significant, as the precision of landmark identification does not greatly alter the results of the cephalometric diagnosis (38,54). However, the assessment of growth and treatment outcome does require proper identification of landmarks and utilization of landmarks that are more easily identified has been recommended (49,56).

### 1.5.4. DIGITAL IMAGING

Traditionally, conventional analog lateral cephalographs have been hand traced and land-marked for cephalometric assessment. This process is often time consuming and prone to considerable rater error (49,58). Today, lateral cephalographs images can be digitized through the use of a flat bed scanner and transparency adaptor. The analog image is converted to pixels, which represent the grayscale of the original image. The image is then represented onto the computer monitor by way of dpi (or dots per inch), which is the equivalent to a pixel. Thus the number of dots is directly proportional to the image detail. As the scanner setting for dpi can be altered, recent studies have demonstrated that a minimal scanner setting of 150 dpi to 300 would provide adequate image detail on the computer monitor for precise landmark identification (41,59). The digitized lateral cephalograph offers similar reliability to that of conventional radiography with respect to landmark identification in a significantly more efficient manner (49,58,60,61). Furthermore the ease of transfer the digitized information for purposes of patient education or professional collaboration is an additional benefit of digitizing lateral cephalograms.

Another form of digitization that has become widespread is the use of digital radiography. Digital radiography uses a similar x-ray source found in conventional analogue radiography, but replaces film with an imaging screen (phosphor) or electronic sensor commonly known as a charge-coupled device (CCD) (39,40). They usually require less radiation, are processed much quicker than conventional radiographic films, and often instantly viewable on a computer. Furthermore, use of digital radiographs eliminates the source of error associated with scanning conventional radiographs. Aside from the additional benefits of rapid accessibility, transferability and manipulation of the images (27,62), digital lateral cephalometric radiography is still prone to projection errors and offers comparable diagnostic value to that of conventional radiographs (32,54,63,64).

### 1.5.5. COMPUTED TOMOGRAPHY (CT)

Since the invention of the first computed tomography (CT) scanner by Godfrey Hounsfield in Britain in 1972 (65), CT scanners have improved in efficiency and sophistication, experiencing widespread use in clinical applications in the medical and scientific field. Modern CT machines today are helical or spiral CT machines, which use a thin, fan-based x-ray beam, generated by a high output, rotating anode. The x-ray source is housed in a gantry chamber and spirals around the patient multiple times as the patient moves through the chamber on a bed. The image data is being recorded in multiple axial slices at 0.4-0.7 mm apart that become stacked together to produce the final volumetric image. Each axial slice requires a full rotation of the x-ray source, and numerous slices are required for image acquisition. The target image is then reconstructed using algorithms into a three-dimensional image, from which any desired perspective or multiplanar slice can be visualized by appropriate software (25,65-68)

CT devices offer high visual contrast and acuity of soft and hard tissues captured in three dimensions. However, due to the fan-based beam utilized, considerable radiation scatter is observed. Despite the contribution of CT in the medical field, adoption of the use of CT machines in dentistry has been hampered by the large radiation doses, prohibitively high cost, space requirements and long scanning time associated with these machines.

### 1.5.6. CONE BEAM COMPUTED TOMOGRAPHY (CBCT)

To address the dental concerns of conventional CT, the cone beam computed tomography was created in 1997 at the Department of Radiology, Nihon University School of Dentistry in Japan (69). Designed specifically for the head and neck region, cone beam computed tomography (CBCT) uses a cone-shaped x-ray beam generated from a low output anode source and an array of either solid-state flat panel or amorphous silicon detectors. Like the conventional CTs, the x-ray source rotates around the head; however due to the cone beam shape of the x-ray every degree of rotation captures an entire image of the face (Figure 1.4). Furthermore a single 360-degree rotation is all this is required for full image acquisition. The CBCT uses a pulsed source of radiation as compared to conventional CT devices, so the exposure time is considerable shorter resulting a radiation exposure of 15-20% of that of conventional CTs and comparable to that of full mouth peri-apical full mouth exposure (9,11,70-72). In addition, the cone beam also produces a more focused beam and considerably less scatter radiation compared to the conventional fan-based CT devices (6). Thus, CBCTs offer improved resolution, less scan time and lower radiation exposure over its larger CT counterpart.

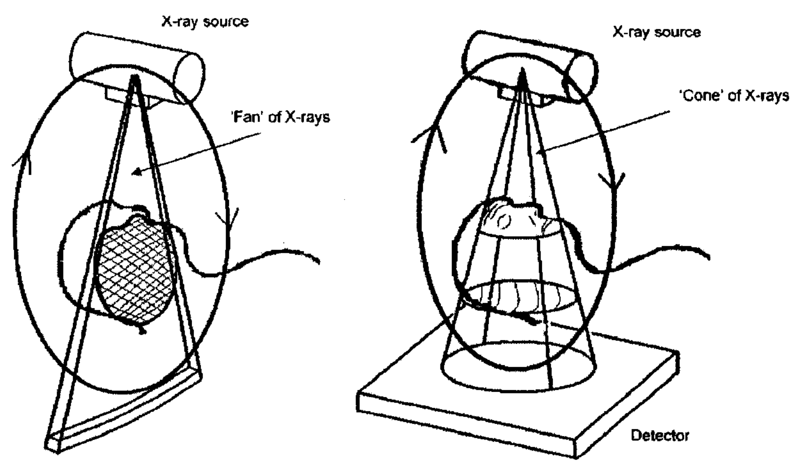



Figure 1.4. Difference between multi-slice CT and CBCT operation (11)

The image obtained from CBCT devices are rendered into a 3D volumetric image comprised of voxels, which are the smallest images produced of the patient's anatomy, possessing a cubic dimension. Once the image is rendered into compliant software, the image can be manipulated to obtain a skull view, regional views, and variations of axial, sagittal or coronal sections. Orthodontic panoramic and lateral cephalometric views can also be generated with a multitude of projection scenarios. The images can be saved as DICOM files for further manipulation using other software (62).

Inherent errors and limitations exist in CBCT. These include background scan noise, image artifacts and the field of view. Artifacts in CBCT data can result from beam scatter of radiodense objects such as metallic restorations and even dense cortical bone. Background noise can be related the geometry of the path of the beam detector. Furthermore the radiation dosage is dependent upon the field of view (FOV), which is the volumetric area that the CBCT x-ray covers. Currently two main FOV are offered with CBCT, nine inch and twelve inch FOVs. Generally, the smaller the FOV used, the less the scatter, better image resolution, and lower radiation exposure is generated (12,25,73-75).

Today, several different CBCT machines are available. These include the Newtom 3G (Quantitative Radiology, Verona, Italy), i-Cat (Imaging Sciences, Hatfield PA, USA), CB MercuRay (Hitachi Medical Corporation, Tokyo, Japan), 3D Accuitomo XYZ (J Morita Mfg. Corp, Kyoto, Japan), Planmeca ProMax 3D (Planmeca, Finland), and the Galileos (Sirona, Charlotte, NC, USA). These CBCT machines can perform a full scan of the head with increased speed of image acquisition and improved resolution over that of conventional x-radiation, offering considerably more information of the internal hard and soft tissue structures of the head (10,25,69,76,77). Due to their small size, high image resolution, three dimensional image accessibility and clinical efficiency, CBCT machines have been used in numerous areas in the field of dentistry including pathology, assessment of bone density in implantology, developmental and periodontal bone defects, oral surgery, endodontics, impacted teeth and root resorption, cleft palate and temporomandibular joint disorders (8,10,24,26,45,69,78-87). CBCT use in orthodontics has been limited to adjunctive procedures such as assessment of potential concerns and complications prior to treatment such as severe facial asymmetries; bone levels for implant placement, identification of impacted or ectopic teeth and presurgical evaluations (78,79). Recently, the advantages of CBCT have incited a surge of interest in the use of CBCT as a substitute for conventional panoramic and cephalometric images for orthodontic treatment planning (25,26,74,76,77,88,89). In an effort to proceed with this endeavor, research comparing the safety and diagnostic parameters of cone beam to conventional radiography has been carried out.

## 1.5.7. CONE BEAM VS CONVENTIONAL RADIOGRAPHY

### 1.5.7.1 RADIATION EXPOSURE

The effects of radiation are long lasting and cumulative over time. The possibility of a pituitary or thyroid damage associated with the risk of low birth weight infants due to maternal exposures to low levels of dental X-rays exemplifies the concern of radiation exposure in dental diagnostic treatment (90). The allowable limit of radiation for a human adult is 3.59 milli Sievert (Sv)/ year and includes all radiation exposures from a multitude of potential sources including daily background radiation, and medical and dental x-rays. On the average only 530 micro Sievert /year or about 1/7$^{th}$ of the allowable radiation obtained from radiation are related to medical and dental exposure (91-94)

During a visit to the orthodontic office, numerous conventional radiographs are taken that constitute the patient records. Published exposure for an analogue full mouth series has been reported as 150 micro Sv; an analogue panoramic radiograph as 54 micro Sv and a lateral cephalographs as 10 micro Sv. Patient exposure dose from a CBCT machine has been reported to be as low as 45 micro Sv to 650 micro Sv (9,71,72,78,95). The resulting effective radiation is dependent upon the settings used including kVp, mA, and field of view. Recent studies have show that the NewTom 9000 can have an effective dose of 40 to 50 micro Sv, which is considerably less than that of other CT modalities and falls within the range of conventional x-rays (9,66,71,72,95). These values of course are dependent upon the field of view of the CBCT device and exposure settings. Studies have demonstrated as much as 60-75% of the dose when using a 9' field of view versus a 12 ' field of view (9,95).

### 1.5.7.2. CEPHALOMETRIC ANALYSIS

In the field of orthodontics, limitations inherent in analyzing three dimensional craniofacial structures from two dimensional x-ray images has generated considerable interest in the potential application of CBCT technology in orthodontic treatment planning (5,11,58,96). While 3D analysis and diagnosis is still in it's infancy, conventional cephalometric analysis on 2D image simulations from 3D volumes may provide a transitional bridge to understanding the potential diagnostic validity of 3D technology, until a 3D analysis is fully developed. To this end, several studies have been launched to assess the precision and accuracy of CBCT images, and to compare the diagnostic reliability of CBCT to that of conventional lateral cephalographs.

Statistical analysis has shown conventional CT 3D cephalometry to be highly reliable and accurate using dry skulls (28,68,97-100). Recent evidence using CBCT has demonstrated similar findings. In a study by Lagravere et al, the precision of landmark identification was assessed in ten adolescent patients using a NewTom QR-DVT 9000. The results demonstrated a high level of repeatable of locating 3D skeletal landmarks (kappa = 0.998) (101). Pinsky et al demonstrated high reliability (ICC=0.96) between five examiners when measuring linear measurements from dry human mandibles imaged on an i-CAT scanner (31). In a recent study by Suomalainen et al, intra-and inter-observer readings showed mean linear measurement error of 4.7% of dry mandibles with an Accuitomo CBCT device (102). Moshiri et al demonstrated higher precision of CBCT generated images using an i-CAT scanner (ICC=0.988) when compared to conventional radiography using dry skulls (ICC=0.713) (103).

Research has also been conducted to examine the accuracy of CBCT devices by comparison to the measurements directly on the imaged object. To assess the accuracy of landmark identification of the Newtom QR-DVT 9000, Lascala et al imaged 8 human skulls and compared the linear measurements to that of the anatomic skull. No significant differences in the measurements between the two sources were noted in the denotmaxillofacial area (104). Using an i-CAT scanner, similar findings were discovered by Pinsky et al with dry human mandibles. In this study, accuracy of linear and volumetric measurements of intraosseous lesions were found to be within 0.5mm ($p<0.01$) and 2.3 $mm^3$ ($\pm$ 2.6 SE) ($p<0.001$), respectively (31). High accuracy of the NewTom (0.07 $\pm$ 0.41 mm) and CB MercuRay (0.00 $\pm$ 0.22mm) cone beam devices were also demonstrated by comparing measurements to dry skulls. In general, the geometric accuracy of linear measurements of images taken from the CBCT devices when compared to the imaged object has demonstrated to be highly accurate (less than 1% error), thus providing a truthful representation of the imaged object (85,86,100,102,105-107,107) (Papadopulous et al, 2005;Robert et al, 2007; Ludlow et al, 2007; Suomalainen et al, 2008; Sratemann et al, 2008).

Comparison to direct physical measures of the imaged object provides the gold standard in research for determining accuracy of a device; however, the clinical diagnostic gold standard in orthodontics is currently the conventional lateral cephalograph. Studies comparing cephalometric measurements between CBCT derived lateral cephalograms and conventional lateral cephalograms from dry skulls showed significantly greater accuracy of the CT imaging as compared to conventional radiography with respect to linear measurements (30,102,103,105,107). Interestingly, no significant difference in angular measurements between the imaging modalities and physical measures were exhibited (98,108)

Although research in assessing the diagnostic value of CBCT is on the rise, studies using humans is scarce. To date, there are only two human studies, which compare the cephalometric measurements between CT generated cephalographs and conventional cephalographs. In a study by Greiner et al, reliability and accuracy of landmarks was assessed using nine patients. In the study, the patients were imaged using a multislice CT scanner and digital radiography. Cephalometric analysis of linear measurements was performed on the respective images. The results of the study demonstrated no significant differences in the reliability or accuracy between the two image modalities (109). In a recent study using 31 human subjects, linear and angular cephalometric measurements between CBCT (NewTom 3G, 12 inch FOV) and conventional lateral cephalographs were compared using Dolphin 3D software. The results of the study showed no statistical differences in the linear and angular measurements between the image modalities, with the exception of Frankfort to mandibular plane angle ($P>0.01$) (110).

## 1.6 REFERENCES


(1) Brodie AG. Cephalometric roentgenology; history, technics and uses. J.Oral Surg.(Chic) 1949 Jul;7(3):185-198.

(2) Baumrind S, Frantz RC. The reliability of head film measurements. 2. Conventional angular and linear measures. Am.J.Orthod. 1971 Nov;60(5):505-517.

(3) Adams J. Correction of error in cephalometric roentgenograms. Angle Orthod. 1940;10(1):3-13.

(4) Mc Gonagle RR. A Review of the Significant Findings in Growth and Development Since the Advent of Cephalometrics. Angle Orthod. ;26(3):155-165.

(5) Salzmann J. Limitations of roentgenographic cephalometrics. Am.J.Orthod. 1964;50(3).

(6) Mah J, Hatcher D. Three-dimensional craniofacial imaging. Am.J.Orthod.Dentofacial Orthop. 2004 Sep;126(3):308-309.

(7) Mah J, Hatcher D. Current status and future needs in craniofacial imaging. Orthod.Craniofac.Res. 2003;6 Suppl 1:10-6; discussion 179-82.

(8) Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur.Radiol. 1998;8(9):1558-1564.

(9) Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac.Radiol. 2006 Jul;35(4):219-226.

(10) Yajima A, Otonari-Yamamoto M, Sano T, Hayakawa Y, Otonari T, Tanabe K, et al. Cone-beam CT (CB Throne) applied to dentomaxillofacial region. Bull.Tokyo Dent.Coll. 2006 Aug;47(3):133-141.

(11) Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J.Can.Dent.Assoc. 2006 Feb;72(1):75-80.

(12) Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. Eur.J.Radiol. 2007 Dec 12. Article in Press

(13) Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod. 1931;1(2):45-66.

(14) Hixon E. The norm concept and cephalometrics. Am.J.Orthod. 1956;42:898-906.

(15) Hixon EH. Cephalometrics: a perspective. Angle Orthod. 1972 Jul;42(3):200-211.

(16) FRANKLIN J. Certain factors of aberration to be considered in clinical roentgenographic cephalometry. Am.J.Orthod. 1952;38:351-368.

(17) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on angular measurements in cephalometry. Eur.J.Orthod. 1988 Nov;10(4):353-361.

(18) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. Eur.J.Orthod. 1986 Aug;8(3):141-148.

(19) Ahlqvist J, Eliasson S, Welander U. The cephalometric projection. Part II. Principles of image distortion in cephalography. Dentomaxillofac.Radiol. 1983;12(2):101-108.

(20) Yoon YJ, Kim KS, Hwang MS, Kim HJ, Choi EH, Kim KW. Effect of head rotation on lateral cephalometric radiographs. Angle Orthod. 2001 Oct;71(5):396-403.

(21) Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. Eur.J.Orthod. 1986 Aug;8(3):149-151.

(22) Malkoc S, Sari Z, Usumez S, Koyuturk AE. The effect of head rotation on cephalometric radiographs. Eur.J.Orthod. 2005 Jun;27(3):315-321.

(23) Halazonetis DJ. From 2-dimensional cephalograms to 3-dimensional computed tomography scans. Am.J.Orthod.Dentofacial Orthop. 2005 May;127(5):627-637.

(24) Misch KA, Yi ES, Sarment DP. Accuracy of cone beam computed tomography for periodontal defect measurements. J.Periodontol. 2006 Jul;77(7):1261-1266.

(25) Small BW. Cone beam computed tomography. Gen.Dent. 2007 May-Jun;55(3):179-181.

(26) Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod.Craniofac.Res. 2003;6 Suppl 1:31-6; discussion 179-82.

(27) Vandenberghe B, Jacobs R, Yang J. Diagnostic validity (or acuity) of 2D CCD versus 3D CBCT-images for assessing periodontal breakdown. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Sep;104(3):395-401.

(28) Lou L, Lagravere MO, Compton S, Major PW, Flores-Mir C. Accuracy of measurements and reliability of landmark identification with computed tomography (CT) techniques in the maxillofacial area: a systematic review. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Sep;104(3):402-411.

(29) Marmulla R, Wortche R, Muhling J, Hassfeld S. Geometric accuracy of the NewTom 9000 Cone Beam CT. Dentomaxillofac.Radiol. 2005 Jan;34(1):28-31.

(30) Mischkowski RA, Pulsfort R, Ritter L, Neugebauer J, Brochhagen HG, Keeve E, et al. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Oct;104(4):551-559.

(31) Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac.Radiol. 2006 Nov;35(6):410-416.

(32) Cohen JM. Comparing digital and conventional cephalometric radiographs. Am.J.Orthod.Dentofacial Orthop. 2005 Aug;128(2):157-160.

(33) McWilliam JS, Welander U. The effect of image quality on the identification of cephalometric landmarks. Angle Orthod. 1978 Jan;48(1):49-56.

(34) Parissis N, Kondylidou-Sidira A, Tsirlis A, Patias P. Conventional radiographs vs digitized radiographs: image quality assessment. Dentomaxillofac.Radiol. 2005 Nov;34(6):353-356.

(35) Platin E. The use of x-ray film by dental professionals in the United States. Tex.Dent.J. 2002 May;119(5):396-400, 402.

(36) Chadwick BL, Dummer PH. Factors affecting the diagnostic quality of bitewing radiographs: a review. Br.Dent.J. 1998 Jan 24;184(2):80-4; discussion 77.

(37) Molander B. Panoramic radiography in dental diagnostics. Swed.Dent.J.Suppl. 1996;119:1-26.

(38) Perillo M, Beideman R, Shofer F, Jacobsson-Hunt U, Higgins-Barber K, Laster L, et al. Effect of landmark identification on cephalometric measurements: guidelines for cephalometric analyses. Clin.Orthod.Res. 2000 Feb;3(1):29-36.

(39) Chen YJ, Chen SK, Huang HW, Yao CC, Chang HF. Reliability of landmark identification in cephalometric radiography acquired by a storage phosphor imaging system. Dentomaxillofac.Radiol. 2004 Sep;33(5):301-306.

(40) Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson LG. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. Eur.J.Orthod. 1998 Jun;20(3):331-340.

(41) Held CL, Ferguson DJ, Gallo MW. Cephalometric digitization: A determination of the minimum scanner settings necessary for precise landmark identification. Am.J.Orthod.Dentofacial Orthop. 2001 May;119(5):472-481.

(42) Na K, Yoon Y, Kim K. A study on the errors in the cephalometric measurements. Korean J Orthod 1998;28(1):75-83.

(43) Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am.J.Orthod. 1971 Aug;60(2):111-127.

(44) Bergersen EO. Enlargement and distortion in cephalometric radiography: compensation tables for linear measurements. Angle Orthod. 1980 Jul;50(3):230-244.

(45) Cascone P, Cicconetti A. Hemifacial microsomia: cephalometric evaluation. Mondo Ortod. 1991 Jul-Aug;16(4):407-417.

(46) Grayson BH, Bookstein FL, McCarthy JG. The mandible in mandibulofacial dysostosis: a cephalometric study. Am.J.Orthod. 1986 May;89(5):393-398.

(47) Midtgard J, Bjork G, Linder-Aronson S. Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances. Angle Orthod. 1974 Jan;44(1):56-61.

(48) Baumrind S, Miller D, Molthen R. The reliability of head film measurements. 3. Tracing superimposition. Am.J.Orthod. 1976 Dec;70(6):617-644.

(49) Kazandjian S, Kiliaridis S, Mavropoulos A. Validity and reliability of a new edge-based computerized method for identification of cephalometric landmarks. Angle Orthod. 2006 Jul;76(4):619-624.

(50) Hagg U, Cooke MS, Chan TC, Tng TT, Lau PY. The reproducibility of cephalometric landmarks: an experimental study on skulls. Aust.Orthod.J. 1998 Oct;15(3):177-185.

(51) Cooke MS, Wei SH. Cephalometric errors: a comparison between repeat measurements and retaken radiographs. Aust.Dent.J. 1991 Feb;36(1):38-43.

(52) Adenwalla ST, Kronman JH, Attarzadeh F. Porion and condyle as cephalometric landmarks--an error study. Am.J.Orthod.Dentofacial Orthop. 1988 Nov;94(5):411-415.

(53) Tng TTH, Chan TCK, Hagg U, Cooke MS. Validity of cephalometric landmarks. An experimental study on human skulls. The European Journal of Orthodontics 2002;16(2):110-120.

(54) Chen YJ, Chen SK, Yao JC, Chang HF. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. Angle Orthod. 2004 Apr;74(2):155-161.

(55) Ghafari J, Baumrind S, Efstratiadis SS. Misinterpreting growth and treatment outcome from serial cephalographs. Clin.Orthod.Res. 1998 Nov;1(2):102-106.

(56) Ghafari J, Engel FE, Laster LL. Cephalometric superimposition on the cranial base: a review and a comparison of four methods. Am.J.Orthod.Dentofacial Orthop. 1987 May;91(5):403-413.

(57) Efstratiadis SS, Cohen G, Ghafari J. Evaluation of differential growth and orthodontic treatment outcome by regional cephalometric superpositions. Angle Orthod. 1999 Jun;69(3):225-230.

(58) Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur.J.Orthod. 2007 Feb;29(1):105-108.

(59) Halazonetis DJ. At what resolution should I scan cephalometric radiographs? Am.J.Orthod.Dentofacial Orthop. 2004 Jan;125(1):118-119.

(60) Chen YJ, Chen SK, Chang HF, Chen KC. Comparison of landmark identification in traditional versus computer-aided digital cephalometry. Angle Orthod. 2000 Oct;70(5):387-392.

(61) Bruntz LQ, Palomo JM, Baden S, Hans MG. A comparison of scanned lateral cephalograms with corresponding original radiographs. Am.J.Orthod.Dentofacial Orthop. 2006 Sep;130(3):340-348.

(62) Decker JD, Bollen AM, Chen CSK. A model for digital archiving of radiographs into a searchable database. American Journal of Orthodontics & Dentofacial Orthopedics 2007;132(6):856-859.

(63) Schulze RK, Gloede MB, Doll GM. Landmark identification on direct digital versus film-based cephalometric radiographs: a human skull study. Am.J.Orthod.Dentofacial Orthop. 2002 Dec;122(6):635-642.

(64) Macri V, Wenzel A. Reliability of landmark recording on film and digital lateral cephalograms. Eur.J.Orthod. 1993 Apr;15(2):137-148.

(65) Beckmann EC. CT scanning the early days. Br.J.Radiol. 2006 Jan;79(937):5-8.

(66) Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac.Radiol. 2004 Mar;33(2):83-86.

(67) Chen CS, Decker JD. CBCT interpretation. Am.J.Orthod.Dentofacial Orthop. 2007 Sep;132(3):277.

(68) Swennen GR, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2006 Sep;130(3):410-416.

(69) Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac.Radiol. 1999 Jul;28(4):245-248.

(70) Tsiklakis K, Donta C, Gavala S, Karayianni K, Kamenopoulou V, Hourdakis CJ. Dose reduction in maxillofacial imaging using low dose Cone Beam CT. Eur.J.Radiol. 2005 Dec;56(3):413-417.

(71) Kiefer H, Lambrecht JT, Roth J. Dose exposure from analog and digital full mouth radiography and panoramic radiography. Schweiz.Monatsschr.Zahnmed. 2004;114(7):687-693.

(72) Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2003 Oct;96(4):508-513.

(73) Kwong JC, Palomo JM, Landers MA, Figueroa A, Hans MG. Image quality produced by different cone-beam computed tomography settings. Am.J.Orthod.Dentofacial Orthop. 2008 Feb;133(2):317-327.

(74) Korbmacher H, Kahl-Nieke B, Schollchen M, Heiland M. Value of two cone-beam computed tomography systems from an orthodontic point of view. J.Orofac.Orthop. 2007 Jul;68(4):278-289.

(75) Sanders MA, Hoyjberg C, Chu CB, Leggitt VL, Kim JS. Common orthodontic appliances cause artifacts that degrade the diagnostic quality of CBCT images. J.Calif.Dent.Assoc. 2007 Dec;35(12):850-857.

(76) Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J.Orthod. 2005 Dec;32(4):282-293.

(77) Holberg C, Steinhauser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. J.Orofac.Orthop. 2005 Nov;66(6):434-444.

(78) Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. J.Calif.Dent.Assoc. 2003 Nov;31(11):825-833.

(79) Hamada Y, Kondoh T, Noguchi K, Iino M, Isono H, Ishii H, et al. Application of limited cone beam computed tomography to clinical assessment of alveolar bone grafting: a preliminary report. Cleft Palate.Craniofac.J. 2005 Mar;42(2):128-137.

(80) Wortche R, Hassfeld S, Lux CJ, Mussig E, Hensley FW, Krempien R, et al. Clinical application of cone beam digital volume tomography in children with cleft lip and palate. Dentomaxillofac.Radiol. 2006 Mar;35(2):88-94.

(81) Arnheiter C, Scarfe WC, Farman AG. Trends in maxillofacial cone-beam computed tomography usage. Oral Radiology 2006;22(2):80-85.

(82) Maverna R, Gracco A. Different diagnostic tools for the localization of impacted maxillary canines: clinical considerations. Prog.Orthod. 2007;8(1):28-44.

(83) Kim SH, Choi YS, Hwang EH, Chung KR, Kook YA, Nelson G. Surgical positioning of orthodontic mini-implants with guides fabricated on models replicated with cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Apr;131(4 Suppl):S82-9.

(84) Fu KY, Zhang WL, Liu DG, Chen HM, Ma XC. Cone beam computed tomography in the diagnosis of temporomandibular joint osteoarthrosis. Zhonghua Kou Qiang Yi Xue Za Zhi 2007 Jul;42(7):417-420.

(85) Haiter-Neto F, Wenzel A, Gotfredsen E. Diagnostic accuracy of cone beam computed tomography scans compared with intraoral image modalities for detection of caries lesions. Dentomaxillofac.Radiol. 2008 Jan;37(1):18-22.

(86) Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J.Endod. 2008 Mar;34(3):273-279.

(87) Matherne RP, Angelopoulos C, Kulild JC, Tira D. Use of cone-beam computed tomography to identify root canal systems in vitro. J.Endod. 2008 Jan;34(1):87-89.

(88) Yoo S, Yin FF. Dosimetric feasibility of cone-beam CT-based treatment planning compared to CT-based treatment planning. Int.J.Radiat.Oncol.Biol.Phys. 2006 Dec 1;66(5):1553-1561.

(89) Maki K, Inou N, Takanishi A, Miller AJ. Computer-assisted simulations in orthodontic diagnosis and the application of a new cone beam X-ray computed tomography. Orthod.Craniofac.Res. 2003;6 Suppl 1:95-101; discussion 179-82.

(90) Farman AG. ALARA still applies. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2005 Oct;100(4):395-397.

(91) Foens CS, Fairobent LA, Guiberteau MJ, Nuclear Regulatory Commission. 10 CFR Part 35: changes to the NRC rule governing the medical use of radioisotopes and implications for radiologic practice. J.Am.Coll.Radiol. 2006 Feb;3(2):96-101.

(92) Jones CG. A review of the history of U.S. radiation protection regulations, recommendations, and standards. Health Phys. 2005 Jun;88(6):697-716.

(93) Jones CG. A review of the history of U.S. radiation protection regulations, recommendations, and standards. Health Phys. 2005 Feb;88(2):105-124.

(94) Windham JR, Kearfott KJ, Mis FJ. Discrepancies in committed effective dose equivalents calculated using U.S. Nuclear Regulatory Commission Regulatory Guide 8.34. Health Phys. 1994 Nov;67(5):486-494.

(95) Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac.Radiol. 2003 Jul;32(4):229-234.

(96) Nakajima A, Murata M, Tanaka E, Arai Y, Fukase Y, Nishi Y, et al. Development of three-dimensional FE modeling system from the limited cone beam CT images for orthodontic tipping tooth movement. Dent.Mater.J. 2007 Nov;26(6):882-891.

(97) Adams GL, Gansky SA, Miller AJ, Harrell WE,Jr, Hatcher DC. Comparison between traditional 2-dimensional cephalometry and a 3-dimensional approach on human dry skulls. Am.J.Orthod.Dentofacial Orthop. 2004 Oct;126(4):397-409.

(98) Chidiac JJ, Shofer FS, Al-Kutoub A, Laster LL, Ghafari J. Comparison of CT scanograms and cephalometric radiographs in craniofacial imaging. Orthod.Craniofac.Res. 2002 May;5(2):104-113.

(99) Swennen G, Barth E, Schutyser F, De Groeve P, Lemaitre A. Three dimensional (3-D) cephalometry. The basics for virtual planning. J Cranio Maxillofac Surg 2004;32:135.

(100) Papadopoulos MA, Jannowitz C, Boettcher P, Henke J, Stolla R, Zeilhofer HF, et al. Three-dimensional fetal cephalometry: an evaluation of the reliability of cephalometric measurements based on three-dimensional CT reconstructions and on dry skulls of sheep fetuses. J.Craniomaxillofac.Surg. 2005 Aug;33(4):229-237.

(101) Lagravere MO, Major PW. Proposed reference point for 3-dimensional cephalometric analysis with cone-beam computerized tomography. Am.J.Orthod.Dentofacial Orthop. 2005 Nov;128(5):657-660.

(102) Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac.Radiol. 2008 Jan;37(1):10-17.

(103) Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG. Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Oct;132(4):550-560.

(104) Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac.Radiol. 2004 Sep;33(5):291-294.

(105) Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac.Radiol. 2008 Feb;37(2):80-93.

(106) Swennen GR, Grimaldi H, Berten JL, Kramer FJ, Dempf R, Schwestka-Polly R, et al. Reliability and validity of a modified lateral cephalometric analysis for evaluation of craniofacial morphology and growth in patients with clefts. J.Craniofac.Surg. 2004 May;15(3):399-412; discussion 413-4.

(107) Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Apr;103(4):534-542.

(108) Kumar V, Ludlow JB, Mol A, Cevidanes L. Comparison of conventional and cone beam CT synthesized cephalograms. Dentomaxillofac.Radiol. 2007 Jul;36(5):263-269.

(109) Greiner M, Greiner A, Hirschfelder U. Variance of landmarks in digital evaluations: comparison between CT-based and conventional digital lateral cephalometric radiographs. J.Orofac.Orthop. 2007 Jul;68(4):290-298.

(110) Kumar V, Ludlow J, Soares Cevidanes LH, Mol A. In Vivo Comparison of Conventional and Cone Beam CT Synthesized Cephalograms. Angle Orthod. 2008 Sep;78(5):873-879.

# Chapter 2

## The Reliability of Angular Cephalometric Measurements of CBCT and Conventional Lateral Radiographs.

## 2.1 INTRODUCTION

Since it's inception in 1930s, the lateral cephalogram has become the one of the most widely adopted diagnostic tools in clinical orthodontics today. From the lateral cephalogram, a wealth of information can be extracted by way of cephalometric analysis, allowing the orthodontist to diagnose dental and skeletal malocclusions, predict growth, and assess treatment outcome (1,2). Despite the ubiquitous use of conventional lateral cephalographs in clinical orthodontics, inherent errors in projection due to magnification and superimposition of anatomical structures exist, often lowering the quality of the radiographic image. Consequently, errors in landmark identification are the predominant error in cephalometric analysis (3-9).

The main problem with projection error stems from the non-parallel nature of the x-rays beams used in dentistry. As a result the image of the object is often magnified, with the side closest to the x-ray source magnified more than the opposite side (9-13). When the two sides of the face are superimposed, it is often difficult to ascertain accurate locations of the skeletal landmarks. The situation becomes even more difficult when the patient exhibits some skeletal asymmetry (4,14,15).

Cephalometric radiography in orthodontics follows a standardized, reproducible head position in relation to the x-ray source and film. Standardized exposure and film developing settings are used to obtain optimal image contrast and density, and physical head-holding devices such as ear rods and a nasal positioner are used to prevent the head from moving or rotating (1,2,8,16). However, since the device contacts the soft tissues of the external earl canal and nasal bridge, the head can be incorrectly positioned within the device. Consequently, alterations in head position, predominantly with respect to rotations towards or away from the x-ray source, have been shown to affect cephalometric measurements (8,16,17). In most instances, severe head rotations are limited by stabilization devices such as ear rods and are often noticed by the operator. Thus the degree of error produced by head misalignment may not prove to be clinically significant with respect to the outcome assessment of cephalometric analysis (16-18).

Difficulty in identifying craniofacial reference points on the lateral cephalograph has been the predominant source of error in cephalometrics (19-22). Consequently, numerous studies have been undertaken to assess the reliability and repeatability of skeletal landmark identification (3,3-5,23-26). As some points are more difficult to identify than others, such as Porion and A point, a systematic pattern of error is present with respect to certain landmarks (19,20,25,27-30). Thus, the specialty of orthodontics has adopted conventional lateral cephalometric analysis in clinical diagnosis with the acceptance of its inherent limitations.

Advancements in medical technology have allowed us to see beyond the limits of two dimensional x-ray images. An application that is rapidly growing in the field of dentistry is the use of cone beam computed tomography (CBCT) (31,32). Like conventional panoramic x-rays, CBCT uses two-dimensional imaging plates; however, instead of a fan shaped x-ray beam, a cone-beam x-ray is employed. The pulsed x-ray source rotates 360 degrees around the patient's head, capturing a series of complete head x-rays on an array of flat panel image plates or silicon screens (32). Thus an image volume is created. The volumetric data is then rendered by computed algorithms and a three dimensional (3D) image of the head is generated by compatible software. Due to the high image resolution, quick image acquisition and 3D image visualization, CBCT technology is flourishing in areas such as implantology (33,34), periodontology (35-37), orthodontics (38-41), cleft lip and palate (42), endodontics (43), temporal mandibular disorders (44,45), oral pathology (46) and oral surgery (34,46).

Images rendered by CBCT can be manipulated to produce a multitude of image slices in the frontal, transverse, saggital planes as well as a myriad three dimensional perspective angles. Orthogonal (parallel x-rays) as well as perspective (fan shaped) images can also be generated (46). Since the image is volumetric in nature, the magnification and misalignment errors of conventional radiographs are not present. Therefore it would be interesting to see whether an image of a lateral cephalograph generated from CBCT volumetric data is subject to landmark identification error as those found in conventional radiographs. Thus the objective of the study was to evaluate and compare the reliability and repeatability of angular cephalometric measurements on lateral cephalograms generated by CBCT and conventional radiography.

## 2.2 MATERIALS AND METHODS

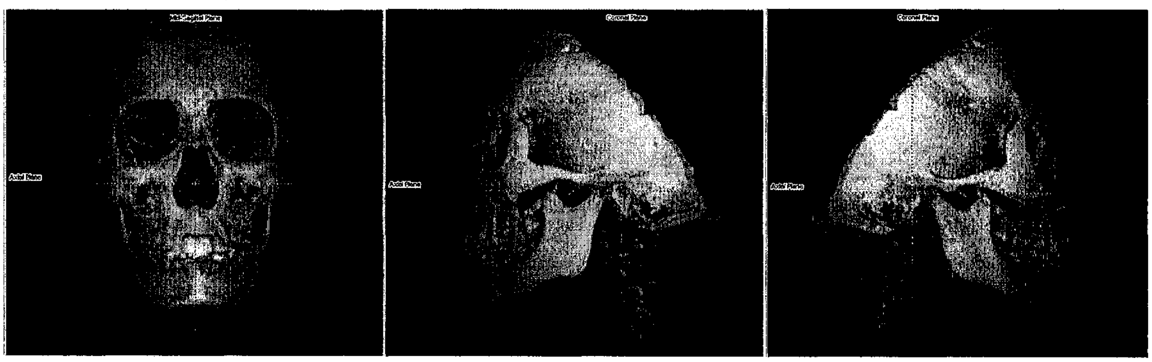
In this diagnostic study, patients were selected by way of sequential sampling from the treatable pool of patients at the Graduate Orthodontic Clinic, Faculty of Medicine and Dentistry, University of Alberta. Patients exhibiting gross asymmetries of the face were excluded from the study to prevent added difficulty in landmark identification. Informed consent from each patient and ethics approval from the Health Research Ethics Board at the University of Alberta was obtained. All patients were imaged using conventional radiography and CBCT. To ensure a proper qualitative analysis of reliability for each imaging modality, ten patients were randomly selected to evaluate intra-rater reliability at three different time points and ten patients were selected to assess inter-rater reliability between three independent raters, for the each of the CBCT and conventional imaging modalities.

To prevent movement of the lower jaw, a radiolucent bite splint was fabricated with a rigid quick set registration material (Bite Registration High Performance, Patterson Dental, St Paul, MN) with the patient in maximum intercuspation. The patients were imaged by both radiographic systems on the same day and the splint was worn throughout the imaging procedures.

Conventional lateral cephalographs were obtained through Orthoceph OC100 (Instrumentarium Imaging, Milwaukee, US). The head was positioned into the apparatus by seating the patient into the attached ear rods and nasal bridge fixation device. The film was processed and scanned at 300 dpi on an

Epson Expression 1680 scanner (Epson America, Long Beach, CA). The image was then imported into Dolphin (Version 10.1, Build 38). CBCT scans were performed on a Newtom 3G Volume Scanner (Quantitative Radiology, Verona, Italy) using a 9 inch field of view with the following settings: kVP (AP) 110, mA (AP) 0.9, kV (LL) 1.20, mA(LL) 1.20, exposure time of 7.2 s and mAs: 7.2. The axial slice thickness was 0.2mm, voxels were isotropic and the volumetric data was converted to DICOM file and subsequently imported into Dolphin 3D.

To obtain a CBCT generated image that most approximated the conventional lateral cephalograph; the 3D head was reconstructed from the volumetric data and carefully oriented in all three planes. The left and right external auditory meatus was lined up to simulate the alignment of the patients head when seated in the OrthoCeph ear rods (Figure 2.1, also see Appendix B for exact orientation).



Frontal Left Right

Figure 2.1. Orientation of CBCT image for x-ray build using 12 inch field of view volumetric sample generated by dolphin 3D

From the volumetric data, a radiographic reconstruction of the lateral cephalograph was obtained using a full thickness scout view of the lateral head. Orthogonal view (parallel x-rays) was selected to eliminate any disproportionate image magnification and superimposition. For the generation of x-ray images from the volumetric data, the maximum intensity projection (MIP) setting was selected. The MIP algorithm has been widely used in the medical field to depict volumetric vascular data acquired by both CT and magnetic resonance imaging (47,48). It offers a pseudo three-dimensional reconstruction and is useful for evaluating areas of high contrast (49). Image magnification has been shown to affect the linear cephalometric measurements when comparing CBCT and conventional radiography (50-52), where as angular measurements have been shown to be generally unaffected by projection magnification (20,53-55). Consequently, only angular measurements were analyzed in this study.

To establish intra-rater reliability, the cephalometric measurements were performed at three weeks apart by the principal investigator. The order of the patients was randomized at each of the time points (T1, T2 and T3). To investigate inter-rater reliability, the results of measurements between three independent raters were compared. For the purpose of the study, ten cephalometric angular measurements that represented skeletal and dental relationships in the vertical and antero-posterior plane were selected (Table 2.1).

Table 2.1. Cephalometric Angles used in the Study

| | |
|---|---|
| SNA | Sella – nasion – A point |
| SNB | Sella – nasion – B point |
| ANB | A point – nasion – B point |
| FMP | Frankfort horizontal – mandibular plane |
| SN-FH | Sella –nasion to Frankfort horizontal |
| SN-Ar | Sella – nasion to articulare |
| Y-axis | Sella – nasion to sella – gnathion |
| U1-PP | Upper incisor to palatal plane |
| L1-MP | Lower incisor to mandibular plane |
| U1-L1 | Upper incisor to lower incisor |

Frankfort horizontal: the line from Porion to Orbitale

## 2.3 STATISTICAL ANALYSIS

For statistical analysis SPSS (version 14.0) was utilized. To test the hypothesis that there is no difference in the cephalometric measurements between the time points (T1, T2 and T3), Intra-Class Correlation Coefficient (ICC) was employed ($\alpha$=0.05). For reliability analysis, the hypothesis that the correlation between the different raters was the same was assessed using Inter-Class Correlation. Single measures reliability and absolute agreement was implemented, with ICC set at 0.8. Correlation values above 0.8 were considered as highly reliable (55).

## 2.4 RESULTS

### Intra-Rater Reliability

Statistical analysis revealed high intra-rater correlation coefficients between measurements the time points, T1, T2 and T3 in both the Conventional (Table 2.2 and 2.3) and CBCT cephalographs (Table 2.4 and 2.5) (ICC>0.8). Thus, the angular measurements performed by the investigator did not differ significantly between the three time points in both imaging modalities. High intra-rater reliability of landmark identification was demonstrated in both systems.

Table 2.2. Angular measurements (degrees) from conventional radiography images (n=10)

| | Time 1 | | Time 2 | | Time 3 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| SNA | 79.460 | 3.823 | 79.920 | 3.571 | 79.790 | 4.099 |
| SNB | 76.970 | 4.107 | 76.830 | 3.712 | 77.050 | 4.188 |
| ANB | 2.490 | 3.316 | 3.110 | 2.993 | 2.700 | 3.063 |
| SNAr | 124.680 | 4.742 | 125.690 | 5.946 | 125.190 | 4.919 |
| SN-FH | 11.030 | 3.043 | 11.380 | 2.908 | 11.160 | 3.408 |
| Y-Axis | 69.370 | 4.580 | 69.780 | 4.056 | 70.100 | 3.946 |
| SN-MP | 33.910 | 7.0289 | 33.130 | 6.471 | 33.770 | 6.472 |
| U1PP | 114.970 | 5.656 | 115.110 | 5.149 | 115.320 | 5.525 |
| L1MP | 93.220 | 7.236 | 92.890 | 6.974 | 92.890 | 7.010 |
| U1-L1 | 125.510 | 7.830 | 125.300 | 7.049 | 125.340 | 7.218 |

Table 2.3. ICC. Conventional Radiography (n=10)

| | Intraclass Correlation | 95% Confidence Interval | |
|---|---|---|---|
| SNA | .962 | (.898 | .989) |
| SNB | .973 | (.925 | .993) |
| ANB | .951 | (.864 | .986) |
| SNAr | .952 | (.868 | .987) |
| SN-FH | .939 | (.839 | .983) |
| Y-Axis | .940 | (.841 | .983) |
| SN-MP | .979 | (.942 | .994) |
| U1PP | .967 | (.909 | .991) |
| L1MP | .981 | (.947 | .995) |
| U1-L1 | .979 | (.939 | .994) |

Table 2. 4. Angular measurements (degrees) from CBCT (n=10)

| | Time 1 | | Time 2 | | Time 3 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| SNA | 81.340 | 4.333 | 82.080 | 4.365 | 81.730 | 4.163 |
| SNB | 78.820 | 2.497 | 79.150 | 2.967 | 78.940 | 2.895 |
| ANB | 2.640 | 4.173 | 2.930 | 4.197 | 4.120 | 2.446 |
| SNAr | 125.920 | 4.210 | 126.230 | 4.697 | 125.570 | 4.115 |
| SN-FH | 9.380 | 3.389 | 9.890 | 3.237 | 10.120 | 3.275 |
| Y-Axis | 68.620 | 3.300 | 69.060 | 3.593 | 68.930 | 3.422 |
| SN-MP | 32.720 | 6.022 | 32.480 | 5.670 | 32.140 | 6.310 |
| U1PP | 112.550 | 6.228 | 112.070 | 6.216 | 113.050 | 6.426 |
| L1MP | 96.020 | 10.24 | 96.060 | 9.624 | 96.140 | 9.515 |
| U1-L1 | 127.320 | 9.146 | 128.270 | 8.114 | 127.040 | 9.076 |

Table 2.5. ICC. CBCT

| | Intraclass Correlation | 95% Confidence Interval | |
|---|---|---|---|
| SNA | .978 | (.928 | .994) |
| SNB | .972 | (.924 | .992) |
| ANB | .992 | (.976 | .998) |
| SNAr | .939 | (.840 | .983) |
| SN-FH | .940 | (.836 | .983) |
| Y-Axis | .927 | (.810 | .980) |
| SN-MP | .976 | (.933 | .993) |
| U1PP | .968 | (.911 | .991) |
| L1MP | .985 | (.957 | .996) |
| U1-L1 | .980 | (.939 | .995) |

## Inter-Rater Reliability

To assess reliability of the measurements between the three raters, statistical analysis using Inter-Class Coefficient (ICC) was employed. The three raters consisted of two graduate orthodontic residents and an orthodontist. There was insufficient evidence to support a difference in the measurements between the three raters with the exception of SN to FH for the Conventional imaging system* (ICC = 0.869, 95% CI: 0.584-0.985) (Table 2.6 and 2.7). A similar trend was noticed with the CBCT imaging system* (ICC=0.831, 95% CI: 0.584-0.950) (Table 2.8 and 2.9).

Table 2.6.Angular measurements (degrees) from conventional radiography images (n=10).

| | Rater 1 | | Rater 2 | | Rater 3 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| SNA | 78.810 | 3.879 | 79.570 | 4.154 | 78.920 | 4.397 |
| SNB | 77.090 | 2.952 | 77.490 | 3.133 | 77.220 | 3.337 |
| ANB | 2.420 | 1.370 | 2.680 | 1.356 | 2.450 | 1.235 |
| SNAr | 122.940 | 5.160 | 122.690 | 4.453 | 122.490 | 5.360 |
| SN-FH | 11.070 | 2.835 | 10.550 | 2.877 | 9.700 | 2.372 |
| Y-Axis | 69.270 | 3.708 | 68.890 | 3.583 | 68.930 | 3.721 |
| SN-MP | 36.290 | 6.737 | 34.790 | 6.587 | 36.480 | 6.287 |
| U1PP | 107.350 | 5.206 | 107.330 | 4.723 | 107.180 | 4.071 |
| L1MP | 87.700 | 7.517 | 89.280 | 8.435 | 90.210 | 8.713 |
| U1-L1 | 134.960 | 8.145 | 134.060 | 9.427 | 132.730 | 8.565 |

Table 2.7 ICC. Conventional radiography (n=10).

| | Intraclass Correlation | 95% Confidence interval | |
|---|---|---|---|
| SNA | .964 | (.894 | .990) |
| SNB | .974 | (.928 | .993) |
| ANB | .923 | (.800 | .978) |
| SNAr | .959 | (.888 | .989) |
| SN-FH | .869 | (.584* | .965) |
| Y-Axis | .974 | (.927 | .993) |
| SN-MP | .961 | (.835 | .991) |
| U1PP | .930 | (.811 | .980) |

| | | | |
|---|---|---|---|
| L1MP | .944 | (.808 | .985) |
| U1-L1 | .946 | (.840 | .985) |

Table. 2.8. Angular measurements (degrees) from CBCT (n=10)

| | Rater 1 | | Rater 2 | | Rater 3 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| SNA | 79.420 | 3.839 | 79.400 | 3.660 | 79.120 | 4.216 |
| SNB | 76.970 | 4.172 | 76.300 | 4.092 | 76.850 | 4.426 |
| ANB | 3.180 | 2.538 | 3.610 | 2.299 | 3.010 | 2.145 |
| SNAr | 124.680 | 4.742 | 125.440 | 4.610 | 124.580 | 4.805 |
| SN-FH | 10.430 | 2.793 | 10.400 | 2.679 | 9.390 | 2.582 |
| Y-Axis | 69.370 | 4.580 | 69.880 | 4.306 | 69.490 | 4.558 |
| SN-MP | 33.940 | 7.0965 | 34.310 | 6.797 | 35.600 | 6.093 |
| U1PP | 114.480 | 5.198 | 112.970 | 4.709 | 113.380 | 5.064 |
| L1MP | 93.220 | 7.236 | 93.400 | 7.916 | 93.170 | 8.093 |
| U1-L1 | 126.100 | 8.409 | 126.910 | 6.868 | 126.480 | 8.003 |

Table 2.9.ICC. CBCT (n=10).

| | Intraclass Correlation | 95% Confidence interval | |
|---|---|---|---|
| SNA | .935 | (.827 | .982) |
| SNB | .958 | (.884 | .998) |
| ANB | .947 | (.838 | .986) |
| SNAr | .925 | (.804 | .979) |
| SN-FH | .831 | (.584* | .950) |
| Y-Axis | .957 | (.884 | .988) |
| SN-MP | .958 | (.856 | .989) |
| U1PP | .937 | (.799 | .983) |
| L1MP | .972 | (.921 | .992) |
| U1-L1 | .935 | (.827 | .982) |

## 2.5 DISCUSSION

The difficulty of identifying landmarks on cephalometric radiographs is a major confounding variable in cephalometric analysis. Although projection errors due to superimposition of bilateral structures and magnification play a major role, other factors such as the variability in head position, hand tracing, radiographic quality and interpretation of the clinician add to the problems in precision and reliability of landmark identification (2,4,5,10,28,56-59). With the boon of technological advancement in the field of dentistry, the process of digitization has largely replaced conventional hand tracings of cephalographs. As fewer steps are required, the digital process is more efficient (19,60,61). Once the images are digitized by way of scanner or by use of digital radiography, computer assisted landmark identification can be achieved using various analytical software. This process has yielded similar levels of reliability and precision offered by traditional cephalometric analysis (27,57,62-65)

With the development of cone beam technology, the limitations of visualizing a three dimensional object in two dimensions can be resolved. However, CBCT does come with its own limitations including scan noise and image artifacts which can often affect the quality of the image. Scan noise or scatter is largely related to the inherent geometry of the x-ray beam and sensors, and image artifacts are usually related to the imaging of radiodense areas such as thick cortical bone and metal restorations or prosthetics (41,66-68). Despite these limitations, CBCT offers numerous advantages over conventional or digital radiography including high image accuracy (69-71), rapid scan times (31,38,72), reduced image artifact using suppression algorithms (68,73), the ability to generate numerous three dimensional or multiplanar images from a single head scan (40,41,74), and the ability to collimate the primary x-ray beam to a specific area of interest (40,41,45). Furthermore, published reports on newer CBCT devices indicate an effective does of radiation, with an average range of 36.9-54 microsievert (μSv), which is similar to that of conventional dental full-mouth radiographs (75-80).

The benefits of CBCT have lead to widespread application in numerous fields of dentistry. With respect to orthodontic diagnosis and treatment planning, the use of CBCT in the field of orthodontics has yet to ascertained. To better understand the diagnostic value of CBCT with respect to orthodontic treatment planning studies evaluating the precision and reliability of conventional computed tomography technology have been undertaken.

A study by Kragsov et al (50), using dry skulls demonstrated greater inter- and intra-observer variation of landmark identification in three-dimensional CT reconstructions when compared to conventional cephalographs. However, in this study, the precision between traditional cephalometric points on the lateral radiographic image were compared to the precision on defining the same cephalometric points in three dimensions (x,y,z planes), thus a third dimension of error was introduced in the CT measurements and may have not represented an equal comparison between the two imaging modalities. Moshiri et al (55), using i-CAT CBCT scanner on dry human skulls, also demonstrated high reliability and precision of landmark identification. The results of the study revealed significantly higher precision with measurements from the synthesized CBCT cephalographs (ICC=0.988 ±

.006) over that of conventional radiography (ICC=0.713 ± 0.111). In general, high levels of inter and intra examiner reliability have been documented with both CBCT and conventional CT generated images of dry human skulls (70,81-84). A systematic review by Lou et al, noted the ability to obtain a high precision of landmark identification using conventional CT and CBCT devices, and that landmark identification error on can be reduced to 0.5 mm for two-dimensional reconstructions from volumetric CT scans with repeated practice (85).

Despite the growing body of evidence illustrating the precision and reliability of landmark identification on CBCT machines, very little research exists with living human subjects in a clinical setting (86). Thus the aim of the study was to evaluate the precision and reliability of cephalometric measurements in lateral cephalographs obtained from CBCT volumetric data and conventional radiography in humans. The results of the study demonstrated a high degree of reproducibility of ten angular cephalometric measurements, between the different time points (T1, T2 and T3), from lateral cephalometric images obtained from both the conventional and NewTom imaging modalities (ICC>0.8, $\alpha$=0.05). In the first part of study, no pattern of measurement variation was displayed at the different time points (T1, T2 and T3). Since a single rater was used for this analysis, a consistent error in landmark identification (lack of accuracy) could have been made at each time point, thus accounting for the high level of repeatability observed. Thus to test subjective rater error, a reliability analysis was performed using three independent raters.

When comparing the cephalometric measurements of the conventional radiographs between the three raters, a high degree of correlation was exhibited for all measurements (ICC >0.8) with the exception of SNFH (ICC= .869, 95% CI: .584 to 0.965). Interestingly, a similar pattern was observed in the measurements from the lateral cephalograph images generated from the CBCT data, which exhibited high levels of reliability between raters with the exception of SNFH (ICC= 0.831, 95% CI: 0.584 to 0.950). In cephalometrics, a systemic pattern of error in identifying landmarks of anatomical points has been established as some anatomic points are more difficult to discern and are often subject to variations in interpretation (6,24,28). Due to superimposition and magnification problems, as well as differential exposure of radiation along the skull, certain landmarks such as A point and Porion have notoriously been associated with subjective rater error (4,21,29). Due to the variation in identifying Porion, the use of stable references other than Frankfort Horizontal (Porion to Orbitale) for cephalometric analysis has been recommended ((24,29,58).

In this study, the variation in SH-FH angle may be attributed to the several factors. For the conventional lateral radiograph, intrinsic projection errors of magnification may have contributed to a lower image quality, however, the CBCT x-ray simulation was constructed using an orthogonal algorithm, which precluded the magnification and distortional aspects of the x-ray beam. It is possible that some of the patients in the study may have had increased complexity and density of skeletal anatomy in the region of the external internal auditory canals, or there may have been asymmetric positions of the bilateral Porions with respect to the external opening of the ear, where the ear rods enter, making Porion difficult to visualize and identify when both sides of the face were superimposed on the x-ray image. It is interesting to note that Rater 3 consistently had a greater deviation in measurement of the SH-FH angle in both systems (Table 5 and Table 7). This however, could be due to the difficulty in identifying Porion and subjective interpretation of the landmark. Another variable that could explain the variation in identifying the SH-FH point is the x-ray construction algorithm used. For the study, the maximum intensity projection (MIP) setting was selected as it produced the least noise, highest contrast ratios and excellent definition of external contours of the skull (47,49,87-90). MIP is a 3D visualization technique that is achieved by evaluating each voxel value along an imaginary projection ray from the observer's eyes within a particular volume of interest and then representing only the highest value as the display value (89). Regions of the skull that are traditionally more difficult to visualize due to contrast and overexposure such as A point, Nasion and the anterior nasal spine (ANS) are accentuated using the MIP algorithm (22,29,47,49,57)). MIPs provide excellent image quality however there is a limitation with this technique as there is a tendency to misrepresent positions that do not have a maximal or attenuated image. Therefore some internal structures such as the Porion and Orbitale, may be obscured which may lead to sub-optimal interpretation of images. Suggestions have been made to consider the use of a limited volume MIP, to allow for improved image contrast and acuity, however the algorithm was not available on the current software (80,88,89).

The data shown here is consistent with the information regarding systematic errors often exhibited with certain landmarks in cephalometric analysis (2,4,9,20,28,29,91). In both the CBCT and conventional imaging modalities, all cephalometric measurements exhibited high reproducibility between raters, with the exception of the SN-FH angle. Although the results indicate insufficient evidence to demonstrate high reliability for SN-FH, the differences in the average measurements of SN-FH (Table 5 and 7) between the raters may not be clinically relevant for diagnosis and treatment planning.

## 2.6 CONCLUSIONS

- The results of the study demonstrate a high level precision and reliability of cephalometric angular measurements in images obtained from both CBCT and conventional radiography.
- Thus CBCT offers a comparable level of reproducibility and reliability of measurements to that of conventional lateral cephalometric radiography.

## 2.7 REFERENCES


(1) Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod. 1931;1(2):45-66.

(2) BRODIE AG. Cephalometric roentgenology; history, technics and uses. J.Oral Surg.(Chic) 1949 Jul;7(3):185-198.

(3) Baumrind S, Miller D, Molthen R. The reliability of head film measurements. 3. Tracing superimposition. Am.J.Orthod. 1976 Dec;70(6):617-644.

(4) Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am.J.Orthod. 1971 Aug;60(2):111-127.

(5) Baumrind S, Frantz RC. The reliability of head film measurements. 2. Conventional angular and linear measures. Am.J.Orthod. 1971 Nov;60(5):505-517.

(6) Cooke MS, Wei SH. Cephalometric errors: a comparison between repeat measurements and retaken radiographs. Aust.Dent.J. 1991 Feb;36(1):38-43.

(7) Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur.J.Orthod. 2007 Feb;29(1):105-108.

(8) Na K, Yoon Y, Kim K. A study on the errors in the cephalometric measurements. Korean J Orthod 1998;28(1):75-83.

(9) Houston WJ. The analysis of errors in orthodontic measurements. Am.J.Orthod. 1983 May;83(5):382-390.

(10) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on angular measurements in cephalometry. Eur.J.Orthod. 1988 Nov;10(4):353-361.

(11) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. Eur.J.Orthod. 1986 Aug;8(3):141-148.

(12) Midtgard J, Bjork G, Linder-Aronson S. Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances. Angle Orthod. 1974 Jan;44(1):56-61.

(13) McWilliam JS, Welander U. The effect of image quality on the identification of cephalometric landmarks. Angle Orthod. 1978 Jan;48(1):49-56.

(14) McCormick SU. Facial asymmetry. The diagnostic challenge. Atlas Oral Maxillofac.Surg.Clin.North Am. 1996 Mar;4(1):1-18.

(15) Cascone P, Cicconetti A. Hemifacial microsomia: cephalometric evaluation. Mondo Ortod. 1991 Jul-Aug;16(4):407-417.

(16) Malkoc S, Sari Z, Usumez S, Koyuturk AE. The effect of head rotation on cephalometric radiographs. Eur.J.Orthod. 2005 Jun;27(3):315-321.

(17) Yoon YJ, Kim KS, Hwang MS, Kim HJ, Choi EH, Kim KW. Effect of head rotation on lateral cephalometric radiographs. Angle Orthod. 2001 Oct;71(5):396-403.

(18) Ahlqvist J, Eliasson S, Welander U. The cephalometric projection. Part II. Principles of image distortion in cephalography. Dentomaxillofac.Radiol. 1983;12(2):101-108.

(19) Turner PJ, Weerakone S. An evaluation of the reproducibility of landmark identification using scanned cephalometric images. J.Orthod. 2001 Sep;28(3):221-229.

(20) Tng TTH, Chan TCK, Hagg U, Cooke MS. Validity of cephalometric landmarks. An experimental study on human skulls. The European Journal of Orthodontics 2002;16(2):110-120.

(21) Perillo M, Beideman R, Shofer F, Jacobsson-Hunt U, Higgins-Barber K, Laster L, et al. Effect of landmark identification on cephalometric measurements: guidelines for cephalometric analyses. Clin.Orthod.Res. 2000 Feb;3(1):29-36.

(22) Trpkova B, Major P, Prasad N, Nebbe B. Cephalometric landmarks identification and reproducibility: a meta analysis. Am.J.Orthod.Dentofacial Orthop. 1997 Aug;112(2):165-170.

(23) Chutimanutskul W, Geenty JP, Shen G, Darendeliler MA. Validity and reliability of ear landmarks as reference points for cephalometric analysis. World J.Orthod. 2007 Summer;8(2):122-128.

(24) Kazandjian S, Kiliaridis S, Mavropoulos A. Validity and reliability of a new edge-based computerized method for identification of cephalometric landmarks. Angle Orthod. 2006 Jul;76(4):619-624.

(25) Chen YJ, Chen SK, Huang HW, Yao CC, Chang HF. Reliability of landmark identification in cephalometric radiography acquired by a storage phosphor imaging system. Dentomaxillofac.Radiol. 2004 Sep;33(5):301-306.

(26) Nimkarn Y, Miles PG. Reliability of computer-generated cephalometrics. Int.J.Adult Orthodon.Orthognath.Surg. 1995;10(1):43-52.

(27) Chen YJ, Chen SK, Yao JC, Chang HF. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. Angle Orthod. 2004 Apr;74(2):155-161.

(28) Hagg U, Cooke MS, Chan TC, Tng TT, Lau PY. The reproducibility of cephalometric landmarks: an experimental study on skulls. Aust.Orthod.J. 1998 Oct;15(3):177-185.

(29) Adenwalla ST, Kronman JH, Attarzadeh F. Porion and condyle as cephalometric landmarks--an error study. Am.J.Orthod.Dentofacial Orthop. 1988 Nov;94(5):411-415.

(30) Macri V, Wenzel A. Reliability of landmark recording on film and digital lateral cephalograms. Eur.J.Orthod. 1993 Apr;15(2):137-148.

(31) Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac.Radiol. 1999 Jul;28(4):245-248.

(32) Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur.Radiol. 1998;8(9):1558-1564.

(33) Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. J.Calif.Dent.Assoc. 2003 Nov;31(11):825-833.

(34) Kim SH, Choi YS, Hwang EH, Chung KR, Kook YA, Nelson G. Surgical positioning of orthodontic mini-implants with guides fabricated on models replicated with cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Apr;131(4 Suppl):S82-9.

(35) Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J.Endod. 2008 Mar;34(3):273-279.

(36) Vandenberghe B, Jacobs R, Yang J. Diagnostic validity (or acuity) of 2D CCD versus 3D CBCT-images for assessing periodontal breakdown. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Sep;104(3):395-401.

(37) Misch KA, Yi ES, Sarment DP. Accuracy of cone beam computed tomography for periodontal defect measurements. J.Periodontol. 2006 Jul;77(7):1261-1266.

(38) Korbmacher H, Kahl-Nieke B, Schollchen M, Heiland M. Value of two cone-beam computed tomography systems from an orthodontic point of view. J.Orofac.Orthop. 2007 Jul;68(4):278-289.

(39) Nakajima A, Murata M, Tanaka E, Arai Y, Fukase Y, Nishi Y, et al. Development of three-dimensional FE modeling system from the limited cone beam CT images for orthodontic tipping tooth movement. Dent.Mater.J. 2007 Nov;26(6):882-891.

(40) Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J.Orthod. 2005 Dec;32(4):282-293.

(41) Holberg C, Steinhauser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. J.Orofac.Orthop. 2005 Nov;66(6):434-444.

(42) Wortche R, Hassfeld S, Lux CJ, Mussig E, Hensley FW, Krempien R, et al. Clinical application of cone beam digital volume tomography in children with cleft lip and palate. Dentomaxillofac.Radiol. 2006 Mar;35(2):88-94.

(43) Matherne RP, Angelopoulos C, Kulild JC, Tira D. Use of cone-beam computed tomography to identify root canal systems in vitro. J.Endod. 2008 Jan;34(1):87-89.

(44) Fu KY, Zhang WL, Liu DG, Chen HM, Ma XC. Cone beam computed tomography in the diagnosis of temporomandibular joint osteoarthrosis. Zhonghua Kou Qiang Yi Xue Za Zhi 2007 Jul;42(7):417-420.

(45) Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am.J.Orthod.Dentofacial Orthop. 2005 Dec;128(6):803-811.

(46) Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. Eur.J.Radiol. 2007 Dec 12.

(47) Raman R, Napel S, Rubin GD. Curved-slab maximum intensity projection: method and evaluation. Radiology 2003 Oct;229(1):255-260.

(48) Marks MP, Napel S, Jordan JE, Enzmann DR. Diagnosis of carotid artery disease: preliminary experience with maximum-intensity-projection spiral CT angiography. AJR Am.J.Roentgenol. 1993 Jun;160(6):1267-1271.

(49) Schreiner S, Paschal CB, Galloway RL. Comparison of projection algorithms used for the construction of maximum intensity projection images. J.Comput.Assist.Tomogr. 1996 Jan-Feb;20(1):56-67.

(50) Kragskov J, Bosch C, Gyldensted C, Sindet-Pedersen S. Comparison of the reliability of craniofacial anatomic landmarks based on cephalometric

radiographs and three-dimensional CT scans. Cleft Palate.Craniofac.J. 1997 Mar;34(2):111-116.

(51) Chidiac JJ, Shofer FS, Al-Kutoub A, Laster LL, Ghafari J. Comparison of CT scanograms and cephalometric radiographs in craniofacial imaging. Orthod.Craniofac.Res. 2002 May;5(2):104-113.

(52) Kumar V, Ludlow JB, Mol A, Cevidanes L. Comparison of conventional and cone beam CT synthesized cephalograms. Dentomaxillofac.Radiol. 2007 Jul;36(5):263-269.

(53) Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac.Radiol. 2004 Sep;33(5):291-294.

(54) Mischkowski RA, Pulsfort R, Ritter L, Neugebauer J, Brochhagen HG, Keeve E, et al. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Oct;104(4):551-559.

(55) Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG. Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Oct;132(4):550-560.

(56) Adams J. Correction of error in cephalometric roentgenograms. Angle Orthod. 1940;10(1):3-13.

(57) Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson LG. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. Eur.J.Orthod. 1998 Jun;20(3):331-340.

(58) Kamoen A, Dermaut L, Verbeeck R. The clinical significance of error measurement in the interpretation of treatment results. Eur.J.Orthod. 2001 Oct;23(5):569-578.

(59) Bergersen EO. Enlargement and distortion in cephalometric radiography: compensation tables for linear measurements. Angle Orthod. 1980 Jul;50(3):230-244.

(60) Davis DN, Mackay F. Reliability of cephalometric analysis using manual and interactive computer methods. Br.J.Orthod. 1991 May;18(2):105-109.

(61) Richardson A. A comparison of traditional and computerized methods of cephalometric analysis. Eur.J.Orthod. 1981;3(1):15-20.

(62) Bruntz LQ, Palomo JM, Baden S, Hans MG. A comparison of scanned lateral cephalograms with corresponding original radiographs. Am.J.Orthod.Dentofacial Orthop. 2006 Sep;130(3):340-348.

(63) Cohen JM. Comparing digital and conventional cephalometric radiographs. Am.J.Orthod.Dentofacial Orthop. 2005 Aug;128(2):157-160.

(64) Halazonetis DJ. At what resolution should I scan cephalometric radiographs? Am.J.Orthod.Dentofacial Orthop. 2004 Jan;125(1):118-119.

(65) Ongkosuwito EM, Katsaros C, van 't Hof MA, Bodegom JC, Kuijpers-Jagtman AM. The reproducibility of cephalometric measurements: a comparison of analogue and digital methods. Eur.J.Orthod. 2002 Dec;24(6):655-665.

(66) Zhang Y, Zhang L, Zhu XR, Lee AK, Chambers M, Dong L. Reducing metal artifacts in cone-beam CT images by preprocessing projection data. Int.J.Radiat.Oncol.Biol.Phys. 2007 Mar 1;67(3):924-932.

(67) Siewerdsen JH, Jaffray DA. Cone-beam computed tomography with a flat-panel imager: magnitude and effects of x-ray scatter. Med.Phys. 2001 Feb;28(2):220-231.

(68) Sanders MA, Hoyjberg C, Chu CB, Leggitt VL, Kim JS. Common orthodontic appliances cause artifacts that degrade the diagnostic quality of CBCT images. J.Calif.Dent.Assoc. 2007 Dec;35(12):850-857.

(69) Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac.Radiol. 2008 Feb;37(2):80-93.

(70) Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac.Radiol. 2008 Jan;37(1):10-17.

(71) Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Apr;103(4):534-542.

(72) Arnheiter C, Scarfe WC, Farman AG. Trends in maxillofacial cone-beam computed tomography usage. Oral Radiology 2006;22(2):80-85.

(73) Farman AG, Scarfe WC. Development of imaging selection criteria and procedures should precede cephalometric assessment with cone-beam

computed tomography. Am.J.Orthod.Dentofacial Orthop. 2006 Aug;130(2):257-265.

(74) Small BW. Cone beam computed tomography. Gen.Dent. 2007 May-Jun;55(3):179-181.

(75) Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2003 Oct;96(4):508-513.

(76) Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac.Radiol. 2006 Jul;35(4):219-226.

(77) Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac.Radiol. 2004 Mar;33(2):83-86.

(78) Kiefer H, Lambrecht JT, Roth J. Dose exposure from analog and digital full mouth radiography and panoramic radiography. Schweiz.Monatsschr.Zahnmed. 2004;114(7):687-693.

(79) Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac.Radiol. 2003 Jul;32(4):229-234.

(80) Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J.Can.Dent.Assoc. 2006 Feb;72(1):75-80.

(81) Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac.Radiol. 2006 Nov;35(6):410-416.

(82) Valeri CJ, Cole TM,3rd, Lele S, Richtsmeier JT. Capturing data from three-dimensional surfaces using fuzzy landmarks. Am.J.Phys.Anthropol. 1998 Sep;107(1):113-124.

(83) Williams FL, Richtsmeier JT. Comparison of mandibular landmarks from computed tomography and 3D digitizer data. Clin.Anat. 2003 Nov;16(6):494-500.

(84) Cavalcanti MG, Rocha SS, Vannier MW. Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. Dentomaxillofac.Radiol. 2004 May;33(3):170-176.

(85) Lou L, Lagravere MO, Compton S, Major PW, Flores-Mir C. Accuracy of measurements and reliability of landmark identification with computed tomography (CT) techniques in the maxillofacial area: a systematic review. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Sep;104(3):402-411.

(86) Lagravere MO, Major PW. Proposed reference point for 3-dimensional cephalometric analysis with cone-beam computerized tomography. Am.J.Orthod.Dentofacial Orthop. 2005 Nov;128(5):657-660.

(87) Mora B, Ebert DS. Low-complexity maximum intensity projection. ACM Transactions on Graphics (TOG) 2005;24(4):1392-1416.

(88) Mroz L, Hauser H, Groller E. Interactive High-Quality Maximum Intensity Projection. Comput.Graphics Forum 2000;19(3):341-350.

(89) Sakas G, Grimm M, Savopoulos A. Optimized Maximum Intensity Projection (MIP). Workshop on Rendering Techniques 1995:51-63.

(90) Zuiderveld K, Koning A, Viergever M. Techniques for speeding up high-quality perspective maximum intensity projection. The international conference on volume image processing on Volume image processing table of contents 1994:507-517.

(91) Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. Eur.J.Orthod. 1986 Aug;8(3):149-151.

(92) Ronald D Kriz, *http://www.sv.vt.edu/classes/ESM4714/methods/FuncExt.html*

# Chapter 3

## A comparative analysis of angular cephalometric values between CBCT generated lateral cephalograph versus conventional lateral cephalographs

## 3.1 INTRODUCTION

Cephalometry is a radiographic technique that is utilized by orthodontists to abstract the human head into a measurable bi-dimensional geometric design. The process of cephalometric analysis involves the identification of anatomical landmarks on a lateral cephalograph, and the subsequent calculation of angular and linear measurements between these points (1,2). From these measurements, inferences with regards to the classification of skeletal and dental morphology, growth pattern and prediction, and treatment outcome can be made. The use of lateral cephalographs in diagnosis and treatment planning has become generally accepted as the standard in clinical orthodontics. Today, the innovation of digital radiography has become more widespread and is now being regularly used in the various fields of dentistry and orthodontics.

Despite the ubiquitous use of lateral cephalometrics, certain limitations and errors exist when capturing a three dimensional object in two dimensions. In lateral cephalometry, errors in identifying landmarks on the head film are considered to be the major sources of error in cephalometric analysis (3-13) X-ray beams are nonparallel and originate from a small source some distance away from the object. Consequently the two-dimensional image captured represents bilateral structures that are disproportionately magnified, due to the divergent profile of the x-ray beam, and superimposed. Furthermore, misalignment of the head also can introduce error into the projected image (14-16). Other factors that contribute to errors in landmark identification include the quality of the radiographic image and variations in subjective operator interpretation, with some landmarks exhibiting a greater pattern of error than others (9,10,17-21). Over the years, these errors have become tolerated and accepted in patient orthodontic diagnosis.

Computed tomography (CT) has found vast application in the medical field, however due to the high cost and radiation levels, CT has found limited use in the dental profession. The desire for a three-dimensional radiographic apparatus to analyze the maxillofacial features has fostered the development of cone beam computed tomography (CBCT) (22,23). Working on a different premise than the conventional CTs, volumetric data is obtained by way of a cone-shaped beam rather than axial or multiple slices. The x-ray source revolves a single 360 degrees around the head, capturing full head images at pulsed intervals on an array of image plates or sensors. The volumetric image is digitally captured and the data is then used to generate a three-dimensional representation of the head by computed algorithms. Using compliant software, the image of the head can be manipulated to render a multitude of three-dimensional perspectives and slices in any axial plane. Furthermore, reconstructions of conventional two-dimensional radiographs, such as a lateral cephalograph or panoramic radiography can easily be reproduced (24-27). Thus, the ability to see beyond the limits of the two dimensionality of x-radiation has enabled great strides in the diagnostic imaging and subsequent treatment modalities in the clinical health field.

Since CBCT was introduced in dentistry, it has experienced widespread growth, significant technological development and numerous clinical applications in the dental field including periodontics, endodontology, cleft palate, implantology, temporal mandibular disorders, oral pathology and oral surgery (25,28-34). New CBCT machines are similar in size to conventional panoramic radiographic machines, and can perform a rapid scan of the head within a range of 10-40s (22,24,25,30,32,35). The quality of the image acquired is similar or often better to that of conventional CTs (23,36,37) and the amount of radiation exposure is up to fifteen times lower than conventional CTs and comparable to that of a full mouth series (27,30,35,38,39) . Thus, diagnosis and treatment planning of various dental procedures involving implant or mini-screw placement, oral surgery, oral pathology, TMD, dental tooth impaction, cleft lip and palate and congenital deformities are now performed with greater detail and precision (24,30,32).

In the field of orthodontics, limitations inherent in analyzing three dimensional craniofacial structures from two dimensional x-ray images has generated considerable interest in the potential application of CBCT technology in orthodontic treatment planning (2-5,24,25,31,35,40-42). Numerous studies evaluating the accuracy of conventional CT machines have demonstrated a high degree of accuracy when compared to physical measures of the human skull, to within 3% of error (43-46). The body of research encompassing the accuracy of CBCT is limited, however new evidence is emerging that suggests CBCT provides highly accurate data compared to the gold standard of linear physical measures directly from dry skulls, demonstrating relative error in the range of 1-2% (36,46-53)

Despite the ability of CBCT to reconstruct highly accurate three-dimensional images of the scanned objects, cephalometric analysis by way of conventional or digitized radiography continues to be the keystone diagnostic tool in clinical orthodontics. Thus a comparative analysis of CBCT generated lateral cephalographs to conventional lateral cephalometry is necessary to delineate the diagnostic validity of CBCT. Several studies investigating the differences between CBCT and conventional cephalographs have demonstrated significantly greater accuracy of linear measurements of CBCT generated images over conventional cephalographs (50,54), while differences in angular measurements were negligible between the image modalities (55,56). In these studies, however, only human skulls were used. Studies are now just emerging, that are investigating the diagnostic precision and accuracy of CBCT devices in humans subjects (69). Thus the goal of this study was to compare the diagnostic value of cone beam CT to conventional lateral cephalometric radiography in humans. The objective was to test the null hypothesis that there is no difference between the measurements of cephalometric angular values between the CBCT and conventional radiography lateral images.

### 3.2 MATERIAL AND METHODS

Thirty-six patients (15 males and 21 females, mean age 23 $\pm$ 12.5 years) were selected by method of convenience sampling through sequential collection from the incoming pool of treatable cases at the University of Alberta Graduate Orthodontic Clinic in Edmonton. Sample size was calculated using the results of a study by Chidiac et al, which compared cephalometric values between CT and lateral cephalometry in human dry skulls (43). Mean differences between several cephalometric measurements values (SNA, ANB, UI-NA and L1MP) and their respective standard deviations were used in the calculation. The following values were used with $\alpha$=0.05 and Power =0.9 (Table 3.1).

Table 3.1. Calculation of Sample size

| Angles | Mean diff | SD | Required sample size |
|---|---|---|---|
| SNA | 0.9 | 1.7 | 40 |
| L1-NB | 4.3 | 7.4 | 34 |
| ANB | 0.9 | 1.6 | 36 |
| U1-NA | 2.8 | 5.4 | 42 |

Based on Chidiac et al, 2002. (43)

Fore each patient an intra-occlusal splint was fabricated using a quick set registration material (Bite Registration High Performance, Patterson Dental, St Paul, MN) to stabilize the occlusion. Each patient was then imaged with both CBCT and conventional radiography on the same day. Informed consent and ethics approval was obtained from the Health Research Ethics Board at the University of Alberta.

A Newtom 3G CBCT Volume Scanner (Quantitative Radiology, Verona, Italy), using a 9 inch field of view with the following settings: kVP (AP) 110, mA (AP) 0.9, kV (LL) 1.20, mA(LL) 1.20, exposure time of 7.2 s and mAs: 7.2 s, was used to generate the volumetric images and conventional lateral cephalographs were generated using an Orthocep OC100 (Instrumentarium Imaging, Milwaukee, US). Both instruments are located at and are property of the Orthodontic Graduate Program at the University of Alberta, Edmonton. The volumetric images from the CBCT were imported as DICOM files to Dolphin 3D (Version 10.1, Build 38), and the analogue lateral cephalographs were digitized by scanning at 350 dpi into an Epson Expression 1680 flat bed scanner (Epson America, Long Beach, CA scanner). The information was downloaded into Dolphin 3D, where the data was analyzed. Patients with visibly noticeable growth asymmetries were not included in the study, as delineation of landmark structures may be difficult to determine on lateral cephalograms.

To obtain a CBCT generated image that most approximated the conventional lateral cephalograph, the digitized, rendered 3D head was orientated so the left and right external auditory meatus was lined up, to simulate the alignment of the patients head when seated in the Orthocep ear rods (Figure 3.1)..

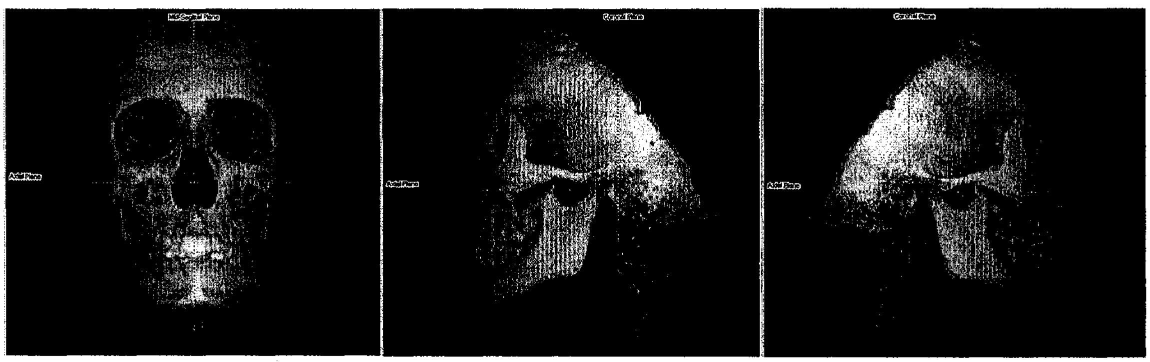


Figure 3.1. Orientation of CBCT image for x-ray build, sample 12" FOV Dolphin 3D.

For the generation of x-ray images from the volumetric data, the maximum intensity projection (MIP) setting was selected. The MIP algorithm has been widely used in the medical field to depict volumetric vascular data acquired by both CT and magnetic resonance imaging (57,58). It offers a pseudo three-dimensional reconstruction and is useful for evaluating areas of high contrast (59).

For the purpose of the study, ten angular measurements between designated skeletal landmarks were compared between the two imaging systems. The cephalometric values to be examined are listed below in Table 3.2. Evidence suggests that projection magnification during conventional imaging does not affect cephalometric angular measurements (55,56). In this study no correction for magnification was performed from images obtained from the OrthoCep100 (Location of the landmarks, Appendix A).

Table 3.2. Cephalometric Angles used in the Study

| | |
|---|---|
| SNA | Sella – nasion – A point |
| SNB | Sella – nasion – B point |
| ANB | A point – nasion – B point |
| FMP | Frankfort horizontal – mandibular plane |
| MP-SN | Mandibular plane to sella -nasion |
| SN-Ar | Sella – nasion to articulare |
| Y-axis | Sella – nasion to sella – gnathion |
| U1-PP | Upper incisor to palatal plane |
| L1-MP | Lower incisor to mandibular plane |
| U1-L1 | Upper incisor to lower incisor |

### 3.3 STATISTICAL ANALYSIS

To assess the differences in the cephalometric measurements between the image modalities, a paired MANOVA was employed with $\alpha$=0.05.

## 3.4 RESULTS

The results of the multivariate test, as shown in Table 3.3, indicate that there is insufficient evidence to support a difference in angular measurements between the lateral cephalograms obtained from conventional radiography and those generated from CBCT data ($p=0.211$, $\alpha=0.05$).

Table 3.3. Differences between angular measurements between Conventional and CBCT images (Conventional – CBCT)

| Measurements Conventional – orthogonal CBCT | Mean | SD | 95% Confidence Interval Lower Bound | Upper Bound | Sig. |
|---|---|---|---|---|---|
| SNA | .272 | 1.494 | -.233 | .778 | .282 |
| SNB | .394 | 1.424 | -.106 | .876 | .106 |
| ANB | -.122 | 1.084 | -.489 | .245 | .503 |
| SNAr | .164 | 3.110 | -.888 | 1.216 | .754 |
| SNFH | -.575 | 1.878 | -1.210 | .060 | .075 |
| AXIS | -.258 | 1.755 | -.852 | .336 | .383 |
| SNMP | -.433 | 2.284 | -1.206 | .340 | .263 |
| UIPP | -.587 | 3.225 | -1.678 | .504 | .282 |
| LIMP | .644 | 3.138 | -.417 | 1.706 | .226 |
| UILI | -.158 | 3.213 | -1.246 | .929 | .769 |

Paired Multivariate test: Wilks' Lambda $p=0.211$, $\alpha=0.05$, $n=36$

In observing the box plot of the differences in the cephalometric measurements between the lateral cephalograph images obtained from conventional and CBCT image modalities (Figure 3.2), we can see the medians resting close to zero. Thus the graph illustrates no significant differences in the cephalometric measurements between the two image modalities.

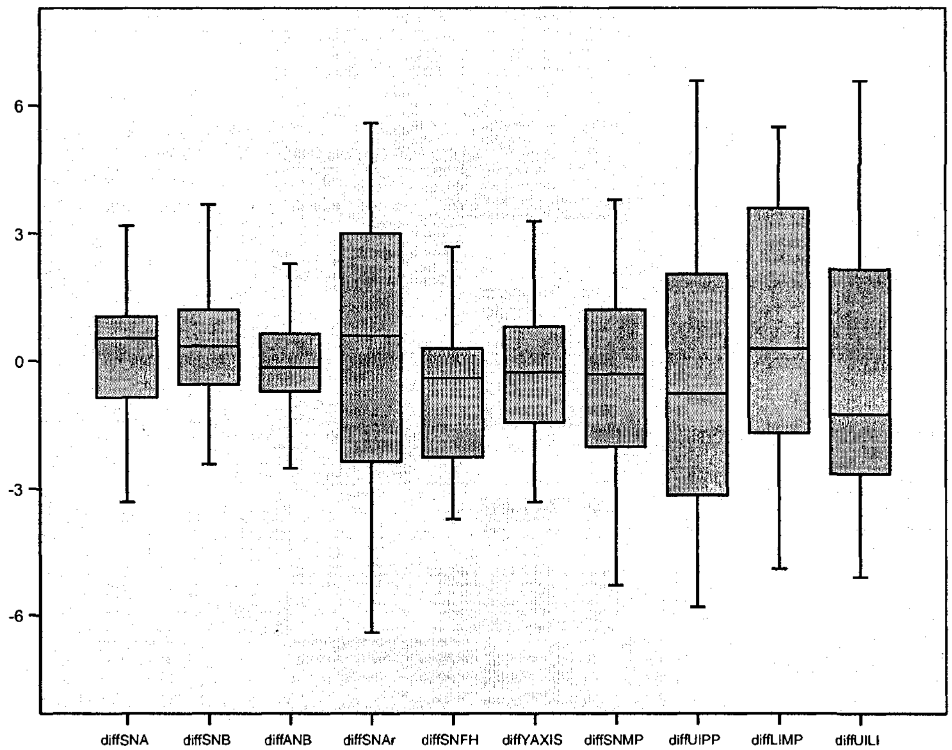



Figure 3.2. Box plot of the differences in angular cephalometric measurements between Conventional and CBCT paired images (Conventional – CBCT)

Although no significant differences between cephalometric measurements from Conventional and CBCT were present, the measurement of SNFH (diffSNFH) did demonstrate the lowest p-value of 0.075. Further analysis comparing SNFH measurements taken between the two imaging modalities is illustrated below in Figure 3.3.

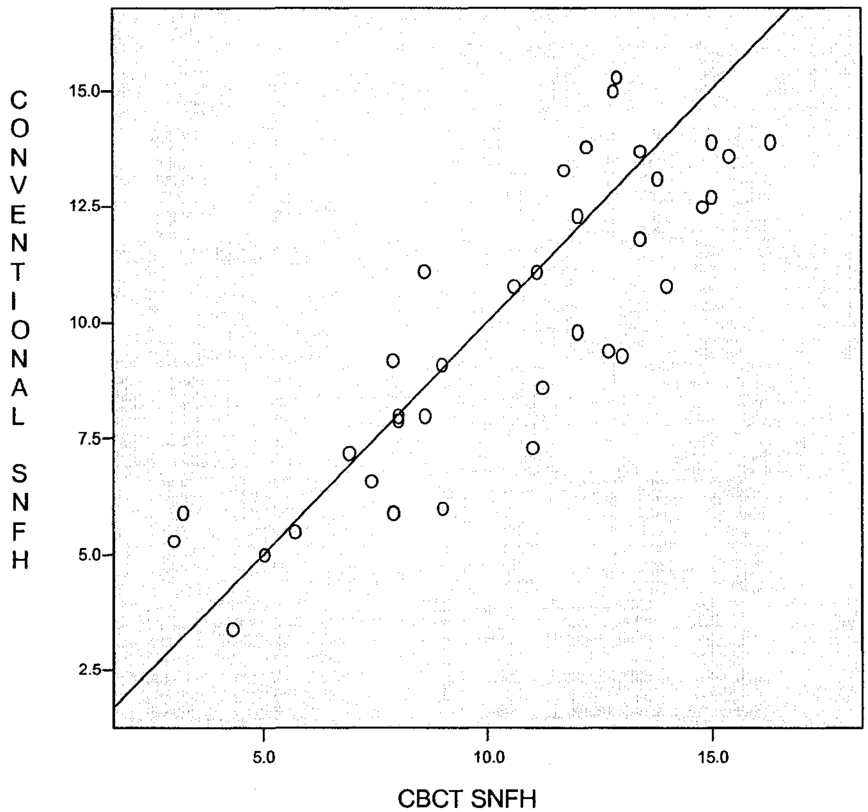



Figure 3.3. Scatter plot of Conventional SNFH vs CBCT SNFH measurement.

The comparison of SNFH values obtained from conventional cephalographs to that of CBCT generated images, as illustrated in the scatter plot in Figure 3, indicates a trend of an over-estimation of the SNFH measurements in the CBCT generated images with respect to a reference line (intercept=0, slope=1). This pattern is corroborated in the general distribution of the difference between the Conventional SNFH and CBCT SNFH values (diffSNFH), which depicts a larger proportion of the distribution slightly below the zero value. (Figure 3.2)

## 3.5 DISCUSSION

Since the introduction of the analogue lateral cephalograph, clinicians in the dental health profession have had to deal with the limitations inherent in capturing a three dimensional object in two dimensions. In the field of orthodontics, projection problems of magnification and superimposition as well as variability in landmark identification have been major sources of error in cephalometry. The development of cone beam technology offers a reprieve from the constraints of two-dimensionality of conventional radiographs, allowing visual access to all facets of the human skull. Designed to be focus on the maxillofacial region (22), CBCT is still in its infancy when compared to its more developed counterpart, the conventional spiral CT. Problems with artifact and background noise are still prevalent in CBCT, however advances in technology continue to improve these elements. As CBCT imaging is unaffected by the projection problems of conventional radiographs, and the image acquisition is independent of the head position of the patient (13,22,25,30,31,60-62), there has been considerable interest in the use of CBCT for orthodontic diagnosis and treatment (35,41,63).

As CBCT technology is relatively new, the limitations and parameters to which three-dimensional reconstructions of the head can be used for orthodontic diagnosis has yet to be fully ascertained. The development of a three-dimensional cephalometric analysis lies within the near future, however cephalometric analysis on conventional two-dimensional images is currently the predominant diagnostic tool in orthodontics. The ability to generated two-dimensional radiographic simulations from CBCT volumetric data provides an opportunity to utilize conventional cephalometric analysis on CBCT generated lateral cephalographs. Thus a comparison of cephalometric measurements from CBCT lateral cephalographs to standard conventional radiography can provide vital information with regards to the diagnostic validity of CBCT imaging in orthodontics, and can be used a transitional diagnostic tool until a three-dimensional cephalometric analysis is developed.

The current body of research evaluating the diagnostic validation of CT technology largely involves studies investigating the accuracy of conventional spiral or multi-slice CT machines to that of direct physical measures to dry human skulls In these studies, CT reconstructed images were shown to have a high level of accuracy to that of the object scanned, demonstrating an almost 1:1 ratio of the image to the midsaggital plane (43,50,64-66). Thus conventional CT technology has demonstrated the ability to accurately reconstruct the scanned object in three dimensions.

Recent studies have been emerging that demonstrate a similar accuracy to that of conventional CT, offered by CBCT machines (48,49,54). In a study by Mischkowski et al (36), the accuracy of a CBCT (Galileos, Sirona dental systems Inc, Germany) was compared to that of a multi-detector row CT scanner (Somatom Sensation 6, Siemens, Germany) using dry human skulls. The results illustrated less than 2% difference between linear measurements between the two imaging modalities, with CT images demonstrating slightly greater accuracy than CBCT. Comparing the accuracy of measurement distance using limited CBCT and helical CT in five cadaver mandibles, Mischkowski et al (36) demonstrated a measurement error of 1.4% and 2.2% ($P < 0.0001$) with the CBCT and CT systems, respectively when compared to direct physical measures. Mozzo et al (23) evaluated geometric accuracy with reference to various reconstruction modalities and different spatial orientations. The reported difference between the true value and general mean value was 0.8-1% for width and 2.2% for height measurements. And in a study by Stratemann et al (48), CBCT systems demonstrated highly accurate data compared to the gold standard of direct measures from human skulls, with less than 1% relative error. Thus, emerging evidence indicates a strong case for the diagnostic potential of CBCT in the dental field, offering a high level of accuracy and reliability demonstrated in the field of periodontics, endodontics, oral pathology, cleft lip and palate, TMJ and oral surgery (22,25,33,44,47,54,61,67,68). However, as conventional lateral cephalometry by way of either analogue or digital radiography continues to prevail as the primary diagnostic tool in orthodontics, a cephalometric comparison between the lateral cephalograph and an approximate 2D synthesized representation from CBCT could yield important information about the role of CBCT in orthodontic diagnosis.

Currently there only a few studies comparing CBCT images to that of conventional lateral cephalographs. A study by Kumar et al, using dry human skulls, compared cephalometric linear and angular measurements from synthesized CBCT lateral cephalograms with those from conventional cephalometric radiographs as well as to direct physical measurements on the skulls (50). Ten skulls were imaged by both a NewTom 3G (QR-NIM srl, Verona, Italy) and conventional radiography and the data was imported into Dolphin 3D for analysis. For the lateral cephalograph reconstruction, orthogonal and perspective projection algorithms were selected. The orthogonal projection creates an image using estimated parallel x-rays, where as the perspective projection imitates the divergent path of conventional x-rays (32). The results of the study showed no differences between the measurements between the image modalities ($p>0.05$) with the exception of mandibular unit length ($p=0.003$). Furthermore, the orthogonal projection provided greater accuracy of measurement for mid-saggital plane dimensions compared to the perspective CBCT and conventional cephalometric images. Moshiri et al, studied the accuracy of linear measurements from conventional digital radiographs and images synthesized from an i-CAT scanner (Imaging Science International, Hatfield, Pa) in human skulls. The results of the study indicated that CBCT was significantly more accurate that the conventional images calculated in the midsaggital plane (56).

A follow up study by Kumar et al, comparing cephalometric measurements of conventional to Cone beam CT (NewTom) synthesize cephalograms, was the first publication in which human subjects were used. Thirty-one patients were imaged and the results of the study demonstrated no statistical differences in twelve linear and five angular measurements between the two modalities ($p>0.1$), with the exception of Frankfort-mandibular plane angle (FMA). In the study, a discrepancy of $4.09 \pm 3.43$ degrees was noted between the mean FMA between the two imaging systems ($p<0.0001$) (50,69).

The current study was undertaken to determine whether cephalometric analysis could be performed on a conventional cephalograph synthesized from volumetric data obtained by CBCT, and to assess the accuracy of the cephalometric measures to that of conventional radiography. At the time, this research was conducted concurrently with that of Kumar et al. In this study only angular measures were selected to avoid problems of image magnification. In addition only the orthogonal view was selected to decrease landmark magnification and superimposition error (25,70). The results of the study demonstrated no significant differences in all ten angular cephalometric measurements between the two image modalities ($p=0.263$, $\alpha=0.05$). Our data corroborates the data provided in the Kumar et al study, which suggests similar or equal diagnostic validity of CBCT to that of conventional cephalographs. In the Kumar study, significant differences in measurements of Frankfort Horizontal to mandibular plane angle (FMA) were present between the two image modalities. Frankfort Horizontal has been shown to exhibit variation due to the difficulties of identifying the Porion (7,71,72). Furthermore, variations in the mandibular plane angle may have been present due to slight movements of the jaw or mandibular asymmetries. The angle, FH-SN, was measured in the present study as Sella to Nasion (SN) provides a more stable and easily identifiable reference (71,72). Despite the slight over-estimation of FH-SN measurements observed in CBCT generated images (Figure 3.3), no difference in FH-SN between the two image modalities was demonstrated ($p>0.05$, $a=0.05$).

## 3.6 CONCLUSIONS

- Approximate conventional cephalograms can be synthesized from volumetric CBCT data by lining up external auditory canal
- Conventional 2D cephalometric analysis can be accurately performed on synthesized cephalographs, yielding no differences in angular measurements to that of conventional radiographs

## 3.7 REFERENCES


(1) Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod. 1931;1(2):45-66.

(2) Brodie AG. Cephalometric roentgenology; history, technics and uses. J.Oral Surg.(Chic) 1949 Jul;7(3):185-198.

(3) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on angular measurements in cephalometry. Eur.J.Orthod. 1988 Nov;10(4):353-361.

(4) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. Eur.J.Orthod. 1986 Aug;8(3):141-148.

(5) Ahlqvist J, Eliasson S, Welander U. The cephalometric projection. Part II. Principles of image distortion in cephalography. Dentomaxillofac.Radiol. 1983;12(2):101-108.

(6) Baumrind S, Frantz RC. The reliability of head film measurements. 2. Conventional angular and linear measures. Am.J.Orthod. 1971 Nov;60(5):505-517.

(7) Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am.J.Orthod. 1971 Aug;60(2):111-127.

(8) Baumrind S, Miller D, Molthen R. The reliability of head film measurements. 3. Tracing superimposition. Am.J.Orthod. 1976 Dec;70(6):617-644.

(9) Chen YJ, Chen SK, Huang HW, Yao CC, Chang HF. Reliability of landmark identification in cephalometric radiography acquired by a storage phosphor imaging system. Dentomaxillofac.Radiol. 2004 Sep;33(5):301-306.

(10) Chen YJ, Chen SK, Yao JC, Chang HF. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. Angle Orthod. 2004 Apr;74(2):155-161.

(11) Hagg U, Cooke MS, Chan TC, Tng TT, Lau PY. The reproducibility of cephalometric landmarks: an experimental study on skulls. Aust.Orthod.J. 1998 Oct;15(3):177-185.

(12) Hixon EH. Cephalometrics: a perspective. Angle Orthod. 1972 Jul;42(3):200-211.

(13) Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. Eur.J.Orthod. 1986 Aug;8(3):149-151.

(14) Malkoc S, Sari Z, Usumez S, Koyuturk AE. The effect of head rotation on cephalometric radiographs. Eur.J.Orthod. 2005 Jun;27(3):315-321.

(15) Yoon YJ, Kim KS, Hwang MS, Kim HJ, Choi EH, Kim KW. Effect of head rotation on lateral cephalometric radiographs. Angle Orthod. 2001 Oct;71(5):396-403.

(16) Major PW, Johnson DE, Hesse KL, Glover KE. Effect of head orientation on posterior anterior cephalometric landmark identification. Angle Orthod. 1996;66(1):51-60.

(17) Perillo M, Beideman R, Shofer F, Jacobsson-Hunt U, Higgins-Barber K, Laster L, et al. Effect of landmark identification on cephalometric measurements: guidelines for cephalometric analyses. Clin.Orthod.Res. 2000 Feb;3(1):29-36.

(18) Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson LG. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. Eur.J.Orthod. 1998 Jun;20(3):331-340.

(19) Trpkova B, Major P, Prasad N, Nebbe B. Cephalometric landmarks identification and reproducibility: a meta analysis. Am.J.Orthod.Dentofacial Orthop. 1997 Aug;112(2):165-170.

(20) Stabrun AE, Danielsen K. Precision in cephalometric landmark identification. Eur.J.Orthod. 1982 Aug;4(3):185-196.

(21) McWilliam JS, Welander U. The effect of image quality on the identification of cephalometric landmarks. Angle Orthod. 1978 Jan;48(1):49-56.

(22) Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac.Radiol. 1999 Jul;28(4):245-248.

(23) Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur.Radiol. 1998;8(9):1558-1564.

(24) Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod.Craniofac.Res. 2003;6 Suppl 1:31-6; discussion 179-82.

(25) Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. Eur.J.Radiol. 2007 Dec 12.

(26) Yajima A, Otonari-Yamamoto M, Sano T, Hayakawa Y, Otonari T, Tanabe K, et al. Cone-beam CT (CB Throne) applied to dentomaxillofacial region. Bull.Tokyo Dent.Coll. 2006 Aug;47(3):133-141.

(27) Mah J, Hatcher D. Three-dimensional craniofacial imaging. Am.J.Orthod.Dentofacial Orthop. 2004 Sep;126(3):308-309.

(28) Matherne RP, Angelopoulos C, Kulild JC, Tira D. Use of cone-beam computed tomography to identify root canal systems in vitro. J.Endod. 2008 Jan;34(1):87-89.

(29) Kim SH, Choi YS, Hwang EH, Chung KR, Kook YA, Nelson G. Surgical positioning of orthodontic mini-implants with guides fabricated on models replicated with cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Apr;131(4 Suppl):S82-9.

(30) Small BW. Cone beam computed tomography. Gen.Dent. 2007 May-Jun;55(3):179-181.

(31) Arnheiter C, Scarfe WC, Farman AG. Trends in maxillofacial cone-beam computed tomography usage. Oral Radiology 2006;22(2):80-85.

(32) Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J.Can.Dent.Assoc. 2006 Feb;72(1):75-80.

(33) Hatcher DC, Dial C, Mayorga C. Cone beam CT for pre-surgical assessment of implant sites. J.Calif.Dent.Assoc. 2003 Nov;31(11):825-833.

(34) Cascone P, Cicconetti A. Hemifacial microsomia: cephalometric evaluation. Mondo Ortod. 1991 Jul-Aug;16(4):407-417.

(35) Holberg C, Steinhauser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. J.Orofac.Orthop. 2005 Nov;66(6):434-444.

(36) Mischkowski RA, Pulsfort R, Ritter L, Neugebauer J, Brochhagen HG, Keeve E, et al. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Oct;104(4):551-559.

(37) Hashimoto K, Kawashima S, Araki M, Iwai K, Sawada K, Akiyama Y. Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT. J.Oral Sci. 2006 Mar;48(1):27-34.

(38) Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac.Radiol. 2004 Mar;33(2):83-86.

(39) Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2003 Oct;96(4):508-513.

(40) Nakajima A, Sameshima GT, Arai Y, Homme Y, Shimizu N, Dougherty HS. Two- and three-dimensional orthodontic imaging using limited cone beam-computed tomography. Angle Orthod. 2005 Nov;75(6):895-903.

(41) Maki K, Inou N, Takanishi A, Miller AJ. Computer-assisted simulations in orthodontic diagnosis and the application of a new cone beam X-ray computed tomography. Orthod.Craniofac.Res. 2003;6 Suppl 1:95-101; discussion 179-82.

(42) Korbmacher H, Kahl-Nieke B, Schollchen M, Heiland M. Value of two cone-beam computed tomography systems from an orthodontic point of view. J.Orofac.Orthop. 2007 Jul;68(4):278-289.

(43) Chidiac JJ, Shofer FS, Al-Kutoub A, Laster LL, Ghafari J. Comparison of CT scanograms and cephalometric radiographs in craniofacial imaging. Orthod.Craniofac.Res. 2002 May;5(2):104-113.

(44) Cavalcanti MG, Rocha SS, Vannier MW. Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. Dentomaxillofac.Radiol. 2004 May;33(3):170-176.

(45) Kragskov J, Bosch C, Gyldensted C, Sindet-Pedersen S. Comparison of the reliability of craniofacial anatomic landmarks based on cephalometric radiographs and three-dimensional CT scans. Cleft Palate.Craniofac.J. 1997 Mar;34(2):111-116.

(46) Richtsmeier JT, Paik CH, Elfert PC, Cole TM,3rd, Dahlman HR. Precision, repeatability, and validation of the localization of cranial landmarks using computed tomography scans. Cleft Palate.Craniofac.J. 1995 May;32(3):217-227.

(47) Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J.Endod. 2008 Mar;34(3):273-279.

(48) Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac.Radiol. 2008 Feb;37(2):80-93.

(49) Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac.Radiol. 2008 Jan;37(1):10-17.

(50) Kumar V, Ludlow JB, Mol A, Cevidanes L. Comparison of conventional and cone beam CT synthesized cephalograms. Dentomaxillofac.Radiol. 2007 Jul;36(5):263-269.

(51) Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Apr;103(4):534-542.

(52) Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac.Radiol. 2006 Nov;35(6):410-416.

(53) Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac.Radiol. 2004 Sep;33(5):291-294.

(54) Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am.J.Orthod.Dentofacial Orthop. 2005 Dec;128(6):803-811.

(55) Kumar V, Ludlow J, Soares Cevidanes LH, Mol A. In Vivo Comparison of Conventional and Cone Beam CT Synthesized Cephalograms. Angle Orthod. 2008 Sep;78(5):873-879.

(56) Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG. Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Oct;132(4):550-560.

(57) Raman R, Napel S, Rubin GD. Curved-slab maximum intensity projection: method and evaluation. Radiology 2003 Oct;229(1):255-260.

(58) Marks MP, Napel S, Jordan JE, Enzmann DR. Diagnosis of carotid artery disease: preliminary experience with maximum-intensity-projection spiral CT angiography. AJR Am.J.Roentgenol. 1993 Jun;160(6):1267-1271.

(59) Schreiner S, Paschal CB, Galloway RL. Comparison of projection algorithms used for the construction of maximum intensity projection images. J.Comput.Assist.Tomogr. 1996 Jan-Feb;20(1):56-67.

(60) Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay): system configuration and physical properties. Dentomaxillofac.Radiol. 2004 Jan;33(1):51-59.

(61) Baumrind S. Current clinical research in orthodontics: a perspective. J.Calif.Dent.Assoc. 2006 Oct;34(10):831-834.

(62) Houston WJ. The analysis of errors in orthodontic measurements. Am.J.Orthod. 1983 May;83(5):382-390.

(63) Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J.Orthod. 2005 Dec;32(4):282-293.

(64) Lou L, Lagravere MO, Compton S, Major PW, Flores-Mir C. Accuracy of measurements and reliability of landmark identification with computed tomography (CT) techniques in the maxillofacial area: a systematic review. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Sep;104(3):402-411.

(65) Papadopoulos MA, Jannowitz C, Boettcher P, Henke J, Stolla R, Zeilhofer HF, et al. Three-dimensional fetal cephalometry: an evaluation of the reliability of cephalometric measurements based on three-dimensional CT reconstructions and on dry skulls of sheep fetuses. J.Craniomaxillofac.Surg. 2005 Aug;33(4):229-237.

(66) Kusnoto B, Evans CA, BeGole EA, de Rijk W. Assessment of 3-dimensional computer-generated cephalometric measurements. Am.J.Orthod.Dentofacial Orthop. 1999 Oct;116(4):390-399.

(67) Wortche R, Hassfeld S, Lux CJ, Mussig E, Hensley FW, Krempien R, et al. Clinical application of cone beam digital volume tomography in children with cleft lip and palate. Dentomaxillofac.Radiol. 2006 Mar;35(2):88-94.

(68) Hamada Y, Kondoh T, Noguchi K, Iino M, Isono H, Ishii H, et al. Application of limited cone beam computed tomography to clinical assessment of alveolar bone grafting: a preliminary report. Cleft Palate.Craniofac.J. 2005 Mar;42(2):128-137.

(69) Kumar V, Ludlow J, Soares Cevidanes LH, Mol A. In Vivo Comparison of Conventional and Cone Beam CT Synthesized Cephalograms. Angle Orthod. 2008 Sep;78(5):873-879.

(70) Farman AG, Scarfe WC. Development of imaging selection criteria and procedures should precede cephalometric assessment with cone-beam

computed tomography. Am.J.Orthod.Dentofacial Orthop. 2006 Aug;130(2):257-265.

(71) Bruntz LQ, Palomo JM, Baden S, Hans MG. A comparison of scanned lateral cephalograms with corresponding original radiographs. Am.J.Orthod.Dentofacial Orthop. 2006 Sep;130(3):340-348.

(72) Adenwalla ST, Kronman JH, Attarzadeh F. Porion and condyle as cephalometric landmarks--an error study. Am.J.Orthod.Dentofacial Orthop. 1988 Nov;94(5):411-415.

# Chapter 4

## General Discussion and Conclusions

## 4. 1 GENERAL DISCUSSION

Differential diagnosis in orthodontic treatment planning initially involves the collection of a series of clinical information including medical and dental history, behavioral assessment, intra-oral and facial photos and radiographs of the head. Currently, lateral and frontal cephalograms together with facial photos are the principal diagnostic imaging techniques employed in clinical orthodontics. Identification of anatomical reference points on a lateral cephalogram allows for a geometric assessment of the face, by way of linear, angular and ratio measurements. This process of cephalometric analysis allows the orthodontist to interpret and evaluate the patient's skeletal and dental morphology, growth and development, and treatment outcome. In dental radiography, inherent errors exist with capturing a spatial object in two dimensions. Major sources of error include the superimposition of bilateral structures, disproportionate magnification of the left and right sides of the face due to the non-parallel nature of the x-ray beam, misalignment of the head in the x-ray field and variations in identifying cephalometric landmarks (1-5). Consequently, these impediments can affect the validity of cephalometric analysis.

The introduction of cone beam computed tomography (CBCT) provides a potential remedy to some of the pitfalls of conventional radiography. CBCT offers rapid image acquisition with greater visual acuity and detail than conventional radiography. Furthermore, multiple planes of view and perspectives of the head can be acquired and visualized by a single 360-degree scan. Today, CBCT machines are similar in size to conventional panoramic machines and thus offer the advantage of being a single unit multi-imaging apparatus. Furthermore, the level of exposure created by CBCT continues to decline, offering similar levels of radiation to that of conventional dental radiographs of the full mouth (6-11). However, before CBCT can be implemented in the clinical treatment planning procedure, a validation process for CBCT is necessary.

An appropriate validation of CBCT with respect to its diagnostic capability in orthodontics would involve the development of a system that could analyze volumetric data. The development of such a system would require the acquisition of a large database of patient volumetric data, from which norms can be established using a three-dimensional cephalometric analysis. Currently no such analysis exists; however the development of a three-dimensional cephalometric analysis is not far in the future. The generation of radiographic reconstructions of lateral cephalograms from volumetric data can be analyzed by conventional cephalometric data and thus provides a simplified method by which the diagnostic properties of CBCT could be tested against conventional radiography. This can serve as an interim validation process, bridging two-dimensional imaging to new three-dimensional imaging, during a transitional period where a more complex three-dimensional analysis could be developed.

The studies of the current research intended to evaluate the diagnostic validity of CBCT in clinical orthodontics by 1) determining and comparing the reliability of cephalometric measurements from lateral cephalogram images obtained from conventional radiography and CBCT; and by 2) determining the difference in cephalometric measurements between conventional radiography and CBCT images from the same patients.

The results of the first study demonstrated high levels of reproducibility of cephalometric measurements at three different time points with both conventional radiographs and the CBCT generated image (ICC>0.8). Inter-rater evaluation also showed high reliability of the angular measurements in nine out of ten angles (ICC>0.8, $\alpha$=0.05). Measurement of FH-SN in cephalographs from both systems exhibited significant inter-rater differences. This finding is consistent with the systematic pattern of error in certain landmarks that are more difficult to identify, such as the Porion and A point (12-14). The results of this study support the growing evidence of the high precision displayed by CBCT machines using dry skulls ((15-19).

Currently, direct measurements of the skull provide the gold standard for accuracy of dental diagnostic tools, however clinically this is not practical nor accurate, since soft tissues and fluid filled spaces may affect the quality of the radiograph. Furthermore, patients, unlike dry skulls, are not static, and minor movements can also potentially introduce alterations in radiographic quality. Despite the established accuracy of CBCT machines (16,20-24), the results of the second part of the research, which compared the differences in measurements between conventional and CBCT generated cephalographs, demonstrated no differences in the ten angular measurements between the imaging modalities ($p>0.05$, $\alpha=0.05$). Our findings corroborate the growing body of research that demonstrates the similar diagnostic accuracy of the CBCT to that of conventional and digital lateral cephalographs (25,26)

## 4.2 STRENGTHS OF THE STUDY

Up until now, studies attempting to compare CBCT and traditional conventional lateral cephalographs have only been done on dry skulls. Furthermore, the primary focus of these studies was the comparison of linear measurements between craniofacial landmarks. Thus magnification projection error had to be accounted before comparing the imaging systems. However, this study represents a more practical analysis by using patients that are currently undergoing orthodontic treatment planning. Furthermore, linear measurements are not commonly used in clinical diagnosis. Since angles are not heavily affected by generalized magnification (26,27), the use of angular measurements in this study provide a more valid comparison of the diagnostic value of CBCT to lateral radiographic cephalogram in a manner that is more attuned to current protocols of orthodontic treatment planning. The results of the study also demonstrate the practicality of obtaining reliable and accurate angular cephalometric measurements from synthesized cephalographs reconstructions by simple alignment of the outer region of the external auditory canals. This research represents an original study that aims to evaluate the precision of angular measurements from CBCT generated lateral cephalographs in humans, and represents a new study that compares cephalometric measurements from CBCT generated lateral cephalographs to conventional radiography in human subjects (26)

## 4.3 LIMITATIONS OF THE STUDY

Once the cone beam device scans the object, the volumetric data can be manipulated to render numerous radiographic reconstructions. One limitation of the study is the use of the maximum intensity projection (MIP) filter utilized for the radiographic reconstruction of the lateral cephalograph. As the filter is designed to delineate areas of high contrast, posterior regions of the skull where there are many structural superimpositions can make identification of areas, like porion, difficult (28-31). Furthermore other filters such as the 'ray sum' filter offered the closest reconstruction to a conventional or digital radiograph (32), however the synthesized images were excellent in delineating high contrast regions and very poor in low contrast regions, making landmarks like A point and nasion, difficult to identify. Use of the limited MIP setting has been recommended (32), where visual manipulations in selected areas could be made, however, the option was not available with the current software.

Another limitation that should be recognized is that the results of the study do not necessarily represent the precision or accuracy of cephalometric landmark identification since the variations of landmark identification has been shown to have a greater significance in research than in cephalometric measurements. (2,14,33). Thus the high reliability and accuracy of cephalometric measurements observed in the study may not be representative of the precision and accuracy of cephalometric landmarks. The ten angles used in the study were selected to their prevalence in the current cephalometric analysis performed at the Graduate Orthodontic Clinic, University of Alberta. More angles could have been investigated to see if a pattern of error with the identification of any other landmarks was present.

Furthermore, in this study, it should be noted that measurement error could have been influenced at different levels throughout the process of obtaining the cephalometric measurements. For the CBCT, this includes variation in orientations of the 3D skull to obtain an x-ray construction and errors involved in scanning the analogue lateral cephalograms to a digital format. Also present were the inherent measurement errors involved in identifying the landmarks for cephalometric analysis in dolphin. It should be noted, however, that these potential sources of error occur throughout the routine clinical treatment planning process, and for the most part are considered acceptable errors in clinical orthodontic diagnosis.

## 4.4 RECOMMENDATIONS FOR FUTURE STUDIES

Studies in the future may include a similar study to the one proposed using cephalometric values derived from an anterior posterior cephalogram. In addition, an evaluative study that aims to compare treatment-planning choices among orthodontists based on CBCT images to that of traditional lateral cephalograms would also shed some light about the diagnostic value of CBCTs in a clinical setting. Since one scan from a CBCT can generate virtually all of the conventional orthodontic x-ray images and with greater resolution, a comparison of panoramic x-rays to those generated by CBCT would also be a useful study. As technology improves, radiation doses decrease, and the price of CBCT equipment becomes more affordable, the potential for cone beam CT to replace conventional radiographs in orthodontic treatment is a tangible possibility. The designation of a stable three dimensional reference point for volumetric analysis cephalometric analysis has already been proposed (34) Thus, future studies aimed at developing three dimensional cephalometric analysis will ultimately allow orthodontists to analyze the three dimensional structures of the craniofacial complex with data based on three dimensional acquisition.

## 4.5 CONCLUSIONS

Due to the considerable technological progress of diagnostic medical imaging devices such as the cone beam CT, the way in which the craniofacial complex is visualized in medicine and dentistry is undergoing a radical change. The decreasing costs and radiation exposure levels of CBCT machines married with the limitations of conventional radiography, provides an impetus for widespread the application of CBCT in the dental field. Resistance to CBCT technology in the field of orthodontics has been due to a dependence on cephalometric analysis from images obtained by traditional radiography. The results of our research demonstrate comparable accuracy and precision of angular measurements from lateral cephalograph images obtained from CBCT volumetric data to that of traditional radiographic cephalographs. Our findings support the growing body of evidence that supports the application of a highly accurate and reliable three-dimensional imaging device in orthodontics (21,26,32,35-38). With the boon of new methods of data transfer, archiving and manipulation with digital imaging and communications in medicine (DICOM) (39), the use of digitized volumetric data obtained from CBCT devices will subsequently have a profound impact on orthodontic diagnosis and treatment planning. No doubt, the transition from conventional radiography to cone beam CT will incite the identification new structural landmarks and an array of new analyses.

## 4.6 REFERENCES


(1) Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur.J.Orthod. 2007 Feb;29(1):105-108.

(2) Kamoen A, Dermaut L, Verbeeck R. The clinical significance of error measurement in the interpretation of treatment results. Eur.J.Orthod. 2001 Oct;23(5):569-578.

(3) Na K, Yoon Y, Kim K. A study on the errors in the cephalometric measurements. Korean J Orthod 1998;28(1):75-83.

(4) Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. Eur.J.Orthod. 1986 Aug;8(3):141-148.

(5) Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. Eur.J.Orthod. 1986 Aug;8(3):149-151.

(6) Yoo S, Yin FF. Dosimetric feasibility of cone-beam CT-based treatment planning compared to CT-based treatment planning. Int.J.Radiat.Oncol.Biol.Phys. 2006 Dec 1;66(5):1553-1561.

(7) Pouliot J, Bani-Hashemi A, Chen J, Svatos M, Ghelmansarai F, Mitschke M, et al. Low-dose megavoltage cone-beam CT for radiation therapy. Int.J.Radiat.Oncol.Biol.Phys. 2005 Feb 1;61(2):552-560.

(8) Tsiklakis K, Donta C, Gavala S, Karayianni K, Kamenopoulou V, Hourdakis CJ. Dose reduction in maxillofacial imaging using low dose Cone Beam CT. Eur.J.Radiol. 2005 Dec;56(3):413-417.

(9) Kiefer H, Lambrecht JT, Roth J. Dose exposure from analog and digital full mouth radiography and panoramic radiography. Schweiz.Monatsschr.Zahnmed. 2004;114(7):687-693.

(10) Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac.Radiol. 2003 Jul;32(4):229-234.

(11) Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2003 Oct;96(4):508-513.

(12) Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am.J.Orthod. 1971 Aug;60(2):111-127.

(13) Adenwalla ST, Kronman JH, Attarzadeh F. Porion and condyle as cephalometric landmarks--an error study. Am.J.Orthod.Dentofacial Orthop. 1988 Nov;94(5):411-415.

(14) Perillo M, Beideman R, Shofer F, Jacobsson-Hunt U, Higgins-Barber K, Laster L, et al. Effect of landmark identification on cephalometric measurements: guidelines for cephalometric analyses. Clin.Orthod.Res. 2000 Feb;3(1):29-36.

(15) Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac.Radiol. 2006 Nov;35(6):410-416.

(16) Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac.Radiol. 2008 Jan;37(1):10-17.

(17) Valeri CJ, Cole TM,3rd, Lele S, Richtsmeier JT. Capturing data from three-dimensional surfaces using fuzzy landmarks. Am.J.Phys.Anthropol. 1998 Sep;107(1):113-124.

(18) Williams FL, Richtsmeier JT. Comparison of mandibular landmarks from computed tomography and 3D digitizer data. Clin.Anat. 2003 Nov;16(6):494-500.

(19) Cavalcanti MG, Rocha SS, Vannier MW. Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. Dentomaxillofac.Radiol. 2004 May;33(3):170-176.

(20) Haiter-Neto F, Wenzel A, Gotfredsen E. Diagnostic accuracy of cone beam computed tomography scans compared with intraoral image modalities for detection of caries lesions. Dentomaxillofac.Radiol. 2008 Jan;37(1):18-22.

(21) Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J.Endod. 2008 Mar;34(3):273-279.

(22) Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac.Radiol. 2008 Feb;37(2):80-93.

(23) Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Apr;103(4):534-542.

(24) Mischkowski RA, Pulsfort R, Ritter L, Neugebauer J, Brochhagen HG, Keeve E, et al. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surg.Oral Med.Oral Pathol.Oral Radiol.Endod. 2007 Oct;104(4):551-559.

(25) Kumar V, Ludlow JB, Mol A, Cevidanes L. Comparison of conventional and cone beam CT synthesized cephalograms. Dentomaxillofac.Radiol. 2007 Jul;36(5):263-269.

(26) Kumar V, Ludlow J, Soares Cevidanes LH, Mol A. In Vivo Comparison of Conventional and Cone Beam CT Synthesized Cephalograms. Angle Orthod. 2008 Sep;78(5):873-879.

(27) Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG. Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography. Am.J.Orthod.Dentofacial Orthop. 2007 Oct;132(4):550-560.

(28) Mora B, Ebert DS. Low-complexity maximum intensity projection. ACM Transactions on Graphics (TOG) 2005;24(4):1392-1416.

(29) Mroz L, Hauser H, Groller E. Interactive High-Quality Maximum Intensity Projection. Comput.Graphics Forum 2000;19(3):341-350.

(30) Schreiner S, Paschal CB, Galloway RL. Comparison of projection algorithms used for the construction of maximum intensity projection images. J.Comput.Assist.Tomogr. 1996 Jan-Feb;20(1):56-67.

(31) Sakas G, Grimm M, Savopoulos A. Optimized Maximum Intensity Projection (MIP). Workshop on Rendering Techniques 1995:51-63.

(32) Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. Eur.J.Radiol. 2007 Dec 12.

(33) Chen YJ, Chen SK, Yao JC, Chang HF. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. Angle Orthod. 2004 Apr;74(2):155-161.

(34) Lagravere MO, Major PW. Proposed reference point for 3-dimensional cephalometric analysis with cone-beam computerized tomography. Am.J.Orthod.Dentofacial Orthop. 2005 Nov;128(5):657-660.

(35) Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac.Radiol. 1999 Jul;28(4):245-248.

(36) Arnheiter C, Scarfe WC, Farman AG. Trends in maxillofacial cone-beam computed tomography usage. Oral Radiology 2006;22(2):80-85.

(37) Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am.J.Orthod.Dentofacial Orthop. 2005 Dec;128(6):803-811.

(38) Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac.Radiol. 2004 Sep;33(5):291-294.

(39) Decker JD, Bollen AM, Chen CSK. A model for digital archiving of radiographs into a searchable database. American Journal of Orthodontics & Dentofacial Orthopedics 2007;132(6):856-859.

# APPENDIX

## APPENDIX A : CEPHALOMETRIC LANDMARKS

Figure 1. Location of Cephalometric Skeletal Landmarks

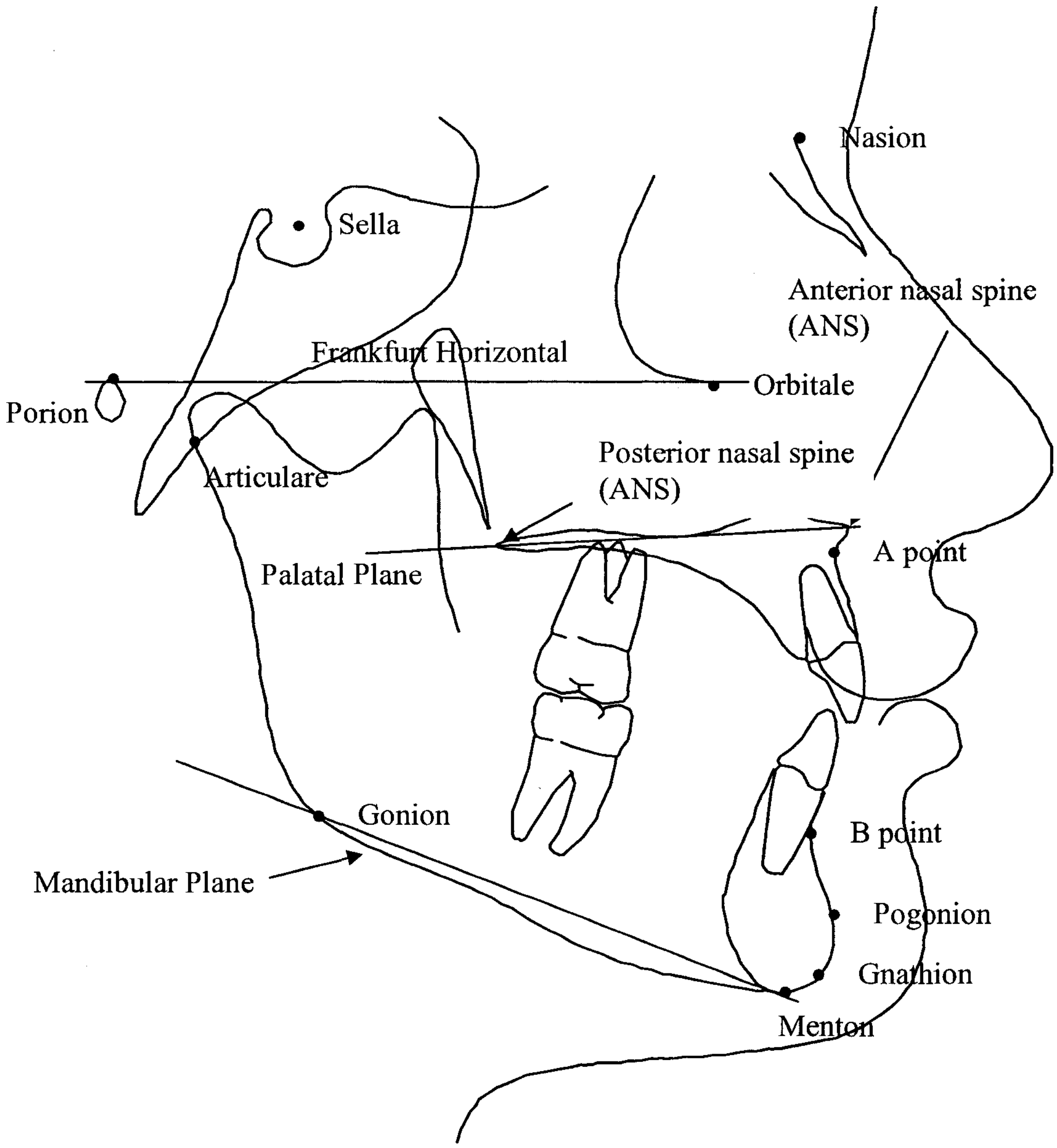


Table 1. Definition of skeletal landmarks

| | |
|---|---|
| Sella | Centre of the pituitary fossa of the sphenoid bone |
| Nasion | Intersection of the internasal suture with the nasofrontal suture in the midsaggital plane |
| Porion | Highest point of the ear canal; most superior point of the external auditory meatus |
| Orbitale | Lowest point of the roof of the orbit; most inferior point of the external border of the orbital cavity |
| Articulare | Most inferior border of the condyle |
| A point | Deepest point of the curve of the maxilla, between the anterior nasal spine and the dental alveolus |
| B point | Most posterior point in the concavity along the anterior border of the symphysis |
| Pogonion | Most anterior point on the mid-saggital symphysis |
| Menton | Most inferior point of the symphysis |
| Gnathion | Midpoint between the most anterior and inferior point of the bony chin |
| Gonion | most convex point where the posterior inferior curve of the ramus meet |

Table 2. Defintion of cephalometric angular measurements

| | |
|---|---|
| SNA | Sella to nasion to point |
| SNB | Sella to nasion to B point |
| ANB | A point to nasion to B point |
| FMP | Frankfort horizontal to mandibular plane |
| SN-FH | Sella - nasion to Frankfort horizontal |
| SN-Ar | Sella - nasion to articulare |
| Y-axis | Sella - nasion to sella - gnathion |
| U1-PP | Upper incisor to palatal plane |
| L1-MP | Lower incisor to mandibular plane |
| U1-L1 | Upper incisor to lower incisor |

## APPENDIX B: DIAGNOSTIC IMAGING APPRATUS

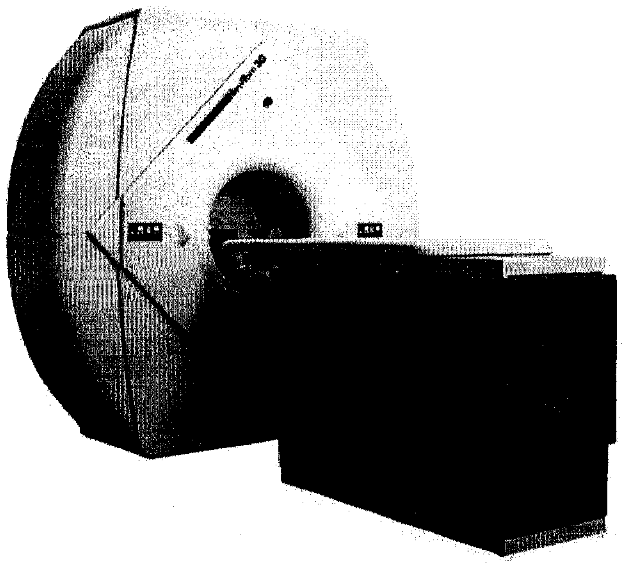


Figure 1. NewTom 3G (Quantitaive Radiology, Verona, Italy)

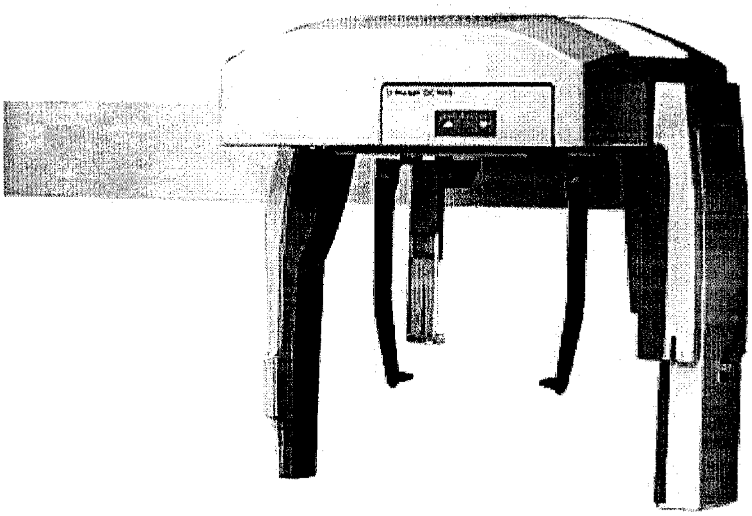


Figure 2. Orthoceph OC100 (Intrumentarium Imaging, Milwaukee, US)

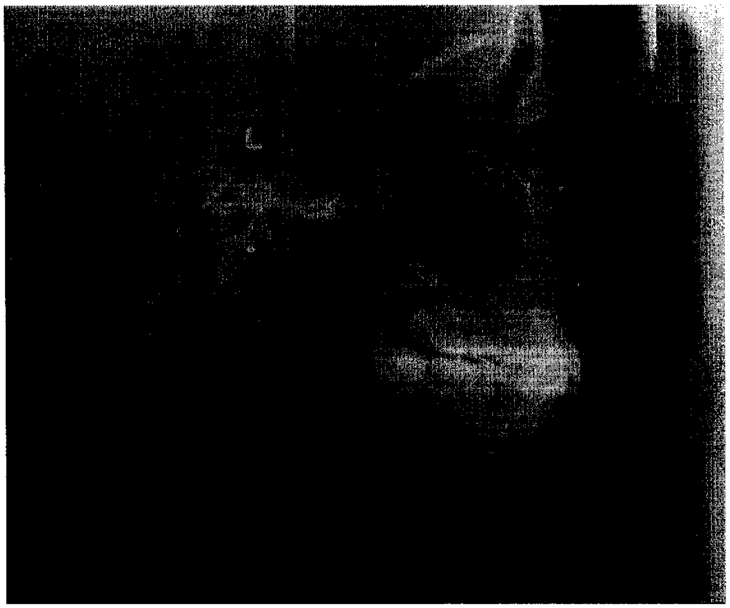
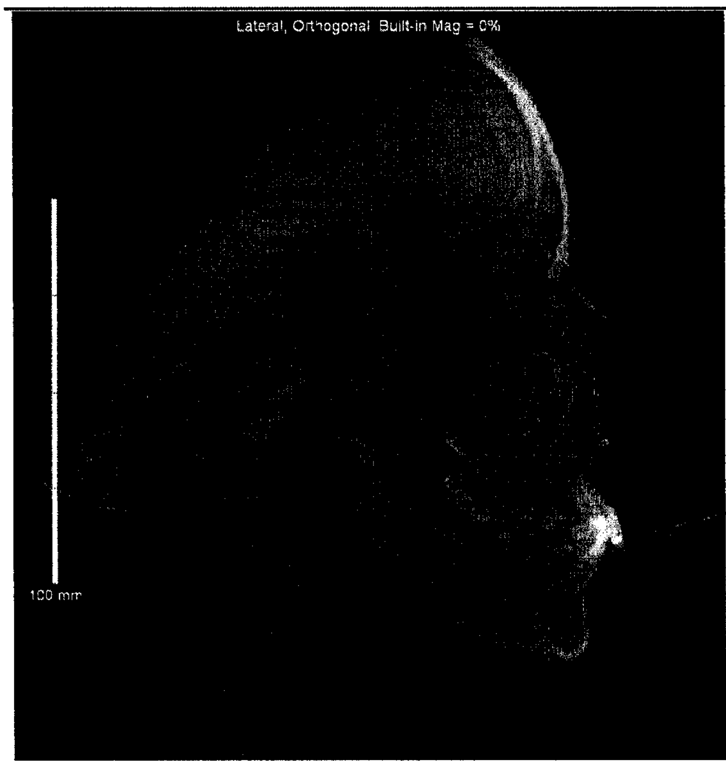
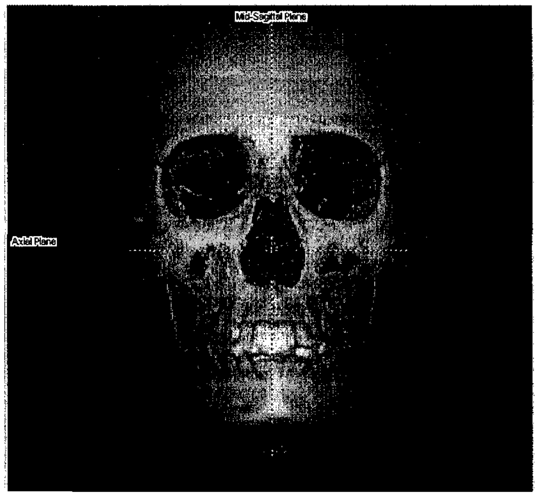


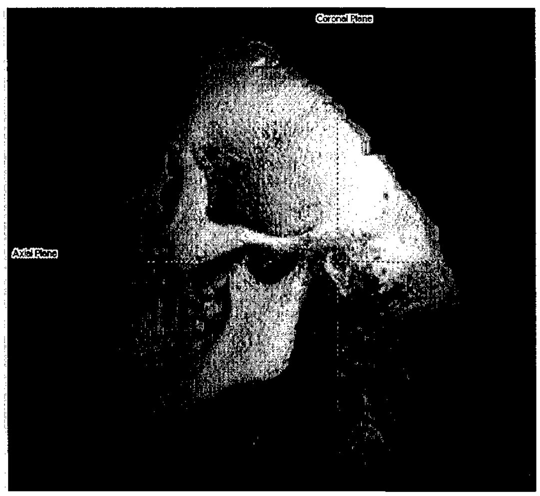
Figure 3. Lateral Cephalograph obtained from Orthoceph OC100




To ensure reproducible occlusion, the patient is wearing a fabricated occlusal splint (Bite Registration High Performance, Patterson Dental) for bite

Figure 4. Lateral Cephalograph reconstruction from NewTom 3G (Maximum Intensity Projection setting) - Orthogonal view.



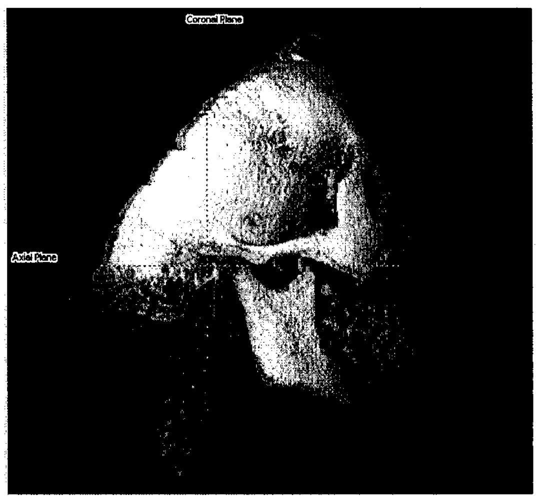
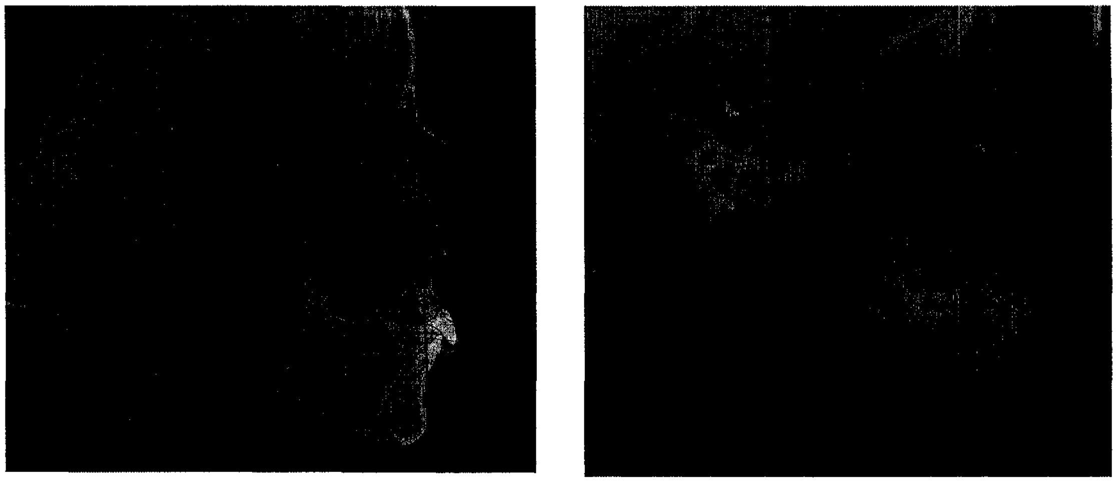




Figure 5. Alignment of volumetric three-dimensional skull for generation of lateral cephalograph reconstruction using Dolphin 3D. The arrows indicated the alignment of the opening of left and right external auditory canal



CBCT

Conventional

Figure 6. Cephalometric Analysis of imported CBCT generated DICOM file and Conventional lateral radiographs using Dolphin and Dolphin 3D (version, build)

Figure 7. Three-dimensional reconstruction of volumetric data on Dolphin 3D

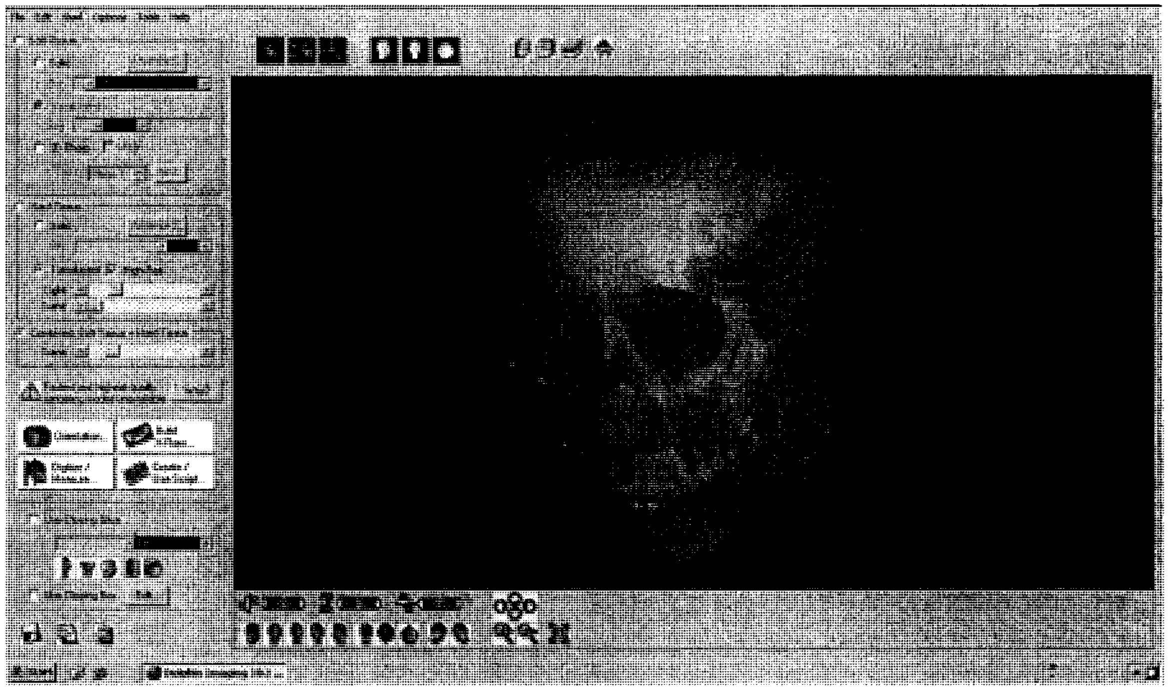


Figure 8. Three-dimensional reconstruction with soft tissue overlay.

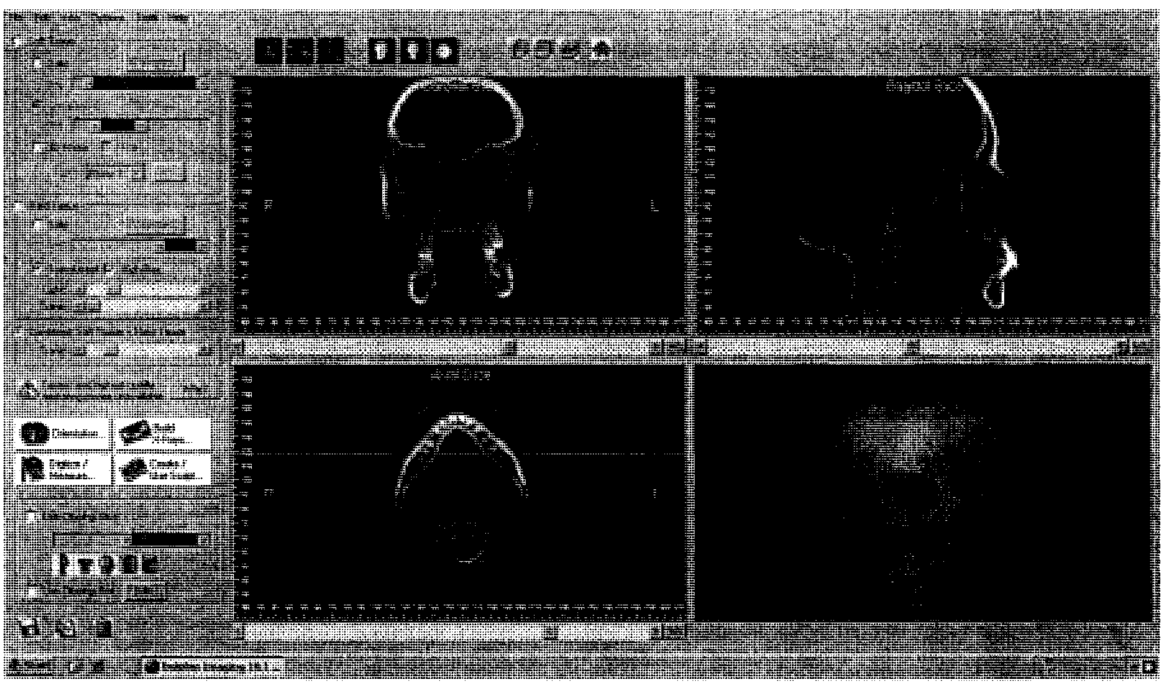


Figure 9. Multiplanar slices (frontal, transverse and saggital) generated from volumetric data