The Effect of Head Position on Crown/Root Ratio Assessed from Panoramic Radiographs

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THESIS

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I dedicate this thesis to the most important and special person in my life – my mother, Natallia Krasinskaya, whose endless support and encouragement continually allows me to accomplish new goals. Her love gives me strength and inspires me every day.

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LIST OF ABBREVIATIONS

2-D	Two-dimensional
3-D	Three-dimensional
ANOVA	Analysis of Variance
ANS	Anterior Nasal Spine
CBCT	Cone Beam Computer Tomography
CEJ	Cementoenamel Junction
FH	Frankfort Horizontal
FMIA	Frankfort Mandibular Incisor Angle
FMX	Full Mouth X-rays
FOV	Field of View
ICC	Intra-class Correlation Coefficient
LC	Lower Canines
LM	Lower Molars
LPm	Lower Premolars
Na	Nasion
UC	Upper Canines
UI	Upper Incisors
UM	Upper Molars
UPm	Upper Premolars

LIST OF MEASUREMENT ABBREVIATIONS

C	Crown
Cm	Mesial segment of the crown of lower molars
Cd	Distal segment of the crown of lower molars
C/R	Crown/root ratio (%)
m	Point of intersection between vertical and horizontal reference lines drawn on the teeth
R	Root
Rm	Mesial root of lower molars
Rd	Distal root of lower molars

SUMMARY

Assessment of crown/root ratio is important in many clinical situations. In orthodontics, practitioners commonly use panoramic radiographs to assess external orthodontically induced apical root resorption. Unfortunately, using panoramic radiographs for this purpose may not lead to reliable and accurate conclusions due to multiple drawbacks of the technique.

This research focuses on assessment of crown/root ratio measurements of teeth from dried skulls and the possible effect of patient positioning in the panoramic machine on the measurements.

We also evaluated the accuracy of the crown/root ratio of incisors and canines measured on panoramic radiographs at ideal head position compared to the same measurements performed on cone beam computer tomographs (CBCT).

The sample consisted of 24 dried skulls. Panoramic and CBCT radiographs were taken. Panoramic radiographs were taken under 7 different head positions. Baseline head position (0°) was established when the horizontal laser orientation line passed through Porion-Orbitale. The skull was then tilted +5°, +10°, +15° upward and -5°, -10, -15° downward. Crown/root ratios of all teeth were measured on panoramic radiographs. Only incisors and canines were measured on the CBCT.

We found upward/downward head tilt to significantly affect crown/root ratio measurements of all groups of teeth except lower incisors. Maxillary teeth were more sensitive to upward head tilt, while downward head tilt was more forgiving, affecting only molars. There were no differences in crown/root ratio measurements of lower incisors and canines between panoramic radiographs at ideal head position and CBCT scans. However, there were differences in crown/root ratio measurements of upper incisors and canines between panoramic radiographs at ideal head position and CBCT scans.

1. INTRODUCTION

1.1 **Background**

Radiographic examination has always been an integral part of dentistry. Nowadays, a large variety of radiographic techniques exist that can provide views of the teeth, roots, bones, and surrounding structures. These radiographs aid in diagnosis and treatment planning of various conditions, from relatively innocuous, such as small caries lesions, to more severe and potentially detrimental, such as cysts and tumors.

In orthodontics, radiographs are used to evaluate the number, size and position of teeth, estimate a patient's stage of development, and assess the prognosis of potential crowding and impactions. Panoramic radiographs are routinely utilized for that purpose. They serve as a vital diagnostic tool, ordered by most clinicians several times throughout treatment. Panoramic and cephalometric radiographs are recommended by most educational programs (Atchison, 1986) and are routinely taken in most orthodontic offices (Tyndall & Turner, 1990). While offering a complete view of the dentition and surrounded structures, panoramic radiographs are less time consuming and have a lower radiation dose compared to full mouth X-rays (FMX). In addition, they are better tolerated by the patient and serve as a good patient education tool (Jansen & Haring JI, 2000). However, in some clinic situations, additional type of radiographs may be required, such as FMX and Cone Beam Computer Tomography (CBCT).

One of the important conditions that can be recognized from panoramic radiographs is root resorption. Root resorption has been widely described in the literature as an undesirable side effect of orthodontic treatment (Andreasen, 1985; Feller, Khammissa, Thomadakis, Fourie, & Lemmer, 2016; Mehta, Deshmukh, Sable, & Patil, 2017; Ousehal, Lazrak, Essmaali, & Ngom, 2012). It is a unique phenomenon mediated by unwanted and uncontrolled activity of hard tissue resorbing cells (Andreasen, 1985). The inflammatory component inherent to this process comes from force application and is the main driving stimulus of orthodontic tooth movement (Brezniak & Wasserstein, 2002; Sawicka, Bedini, Wierzbicki, & Pameijer, 2015).

In histologic studies, the prevalence of root resorption in orthodontically treated patients has been reported to be as high as 90% (Harry & Sims, 1982; McLaughlin, 1964; Stenvik & Mjör, 1970). Much lower numbers have been reported if detected radiographically. Blake et al. (1995) reported the prevalence of root resorption in orthodontic patients at 6-13% for different teeth. This can be explained by the fact that most of the resorption occurs on the surface of the root and can be fully repaired once orthodontic forces are removed (Cheng et al., 2010; Owman-Moll, Kurol, & Lundgren, 1995). In order for root resorption to be detected radiographically, it needs to occur at the apex and to the extent that it causes visible root shortening.

While present to some degree in most orthodontically treated patients, luckily severe root resorption is rare and is found to be associated with only 1-5% of teeth (Weltman, Vig, Fields, Shanker, & Kaizar, 2010).

It is very important to recognize root resorption early, as it can modify treatment and affect prognosis of the teeth. Therefore, a reliable diagnostic method is needed. Unfortunately, there are certain flaws in assessment of root resorption using panoramic radiographs. Two of the most commonly known phenomena inherent to panoramic radiography are magnification and distortion.

Panoramic radiographs have been reported to have up to 20% magnification (Sameshima & Asgarifar, 2001) versus less than 5% of magnification in periapical radiographs (T. A. Larheim & Eggen, 1979). Magnification may vary between panoramic radiographs taken using different machines, and also between different regions of the same radiograph (Abdinian, Soheilipour, Nazeri, & Ghorbanizadeh, 2016; Thanyakarn, Hansen, Rohlin, & Akesson, 1992).

Panoramic radiographs are extremely sensitive to correct patient positioning and distance of the anatomical structures to the focal trough (Dhillon et al., 2012; Kim, Byun, & An, 2014; T. M. Lund & Manson-Hing, 1975; Mckee et al., 2001). By positioning the chin too high, the hard palate becomes superimposed on the roots of the maxillary teeth. If the chin is tilted down, the teeth will appear overlapped (Taylor & Jones, 1995). Moreover, patient position changes the angulation of the teeth in relation to the radiographic film, which may affect the radiographic tooth length.

Assuming that the magnification factor is relatively constant in the vertical axis (T. A. Larheim & Svanaes, 1986), crown and root length should be magnified by the same amount. Thus, using crown/root ratios instead of measuring absolute linear measurements is advantageous in a radiographic study (Hölttä, Nyström, Evälahti, & Alaluusua, 2004).

1.2 **Specific Aims**

This study will help to evaluate the effect of the head position in the panoramic machine on crown/root ratio measurements and evaluate accuracy of the crown/root ratio measurements of incisors and canines performed on panoramic radiographs compared to CBCT scans.

1.3 Significance of the Current Study

Considering the effect of patient positioning in the panoramic machine will help to eliminate a possible source of error in assessment of root resorption. This study will help practitioners critically evaluate root resorption using crown/root ratios on panoramic radiographs. If the method is accurate and reliable, then using ratios instead of absolute measurements will help practitioners overcome the magnification inherent to panoramic radiography.

1.4 Null Hypotheses

Null Hypothesis 1: There is no mean difference in crown/root ratio measurements made on panoramic radiographs for different teeth groups in regard to vertical head tilt in a panoramic machine.

Null Hypothesis 2: There is no mean difference in crown/root ratio measurements of incisors and canines made on panoramic radiographs compared to CBCT scans.

2. REVIEW OF LITERATURE

2.1 General Principles of Panoramic Radiography

The panoramic radiograph is a two-dimensional dental radiograph that produces an image of the entire mouth, where one can observe all the teeth, jaw bones, maxillary sinuses and temporomandibular joints in one image (Perschbacher, 2012). A panoramic unit consists of an X-ray tube that is mounted on one side and the X-ray film that is positioned on the other side. When the exposure is initiated, the unit starts rotating in a semicircle with the X-ray tube moving behind patient's head and the radiographic film moving in front (Leach, Ireland, & Whaites, 2001).

Panoramic radiography is a variation of tomography, a technique that produces an image of the slice of an object, perfectly depicting the structures within the slice, while blurring the structures outside the slice. The film and tube head are connected and rotate simultaneously around a patient in the opposite directions. The axis around which the film and X-ray tube rotate is called the center of rotation. The structures that are located within this area will be clearly visible or in focus. (Figure 1) (Langland, Langlais, McDavid, & DelBalso, 1989; Vivian E Rushton & Rout, 2006).

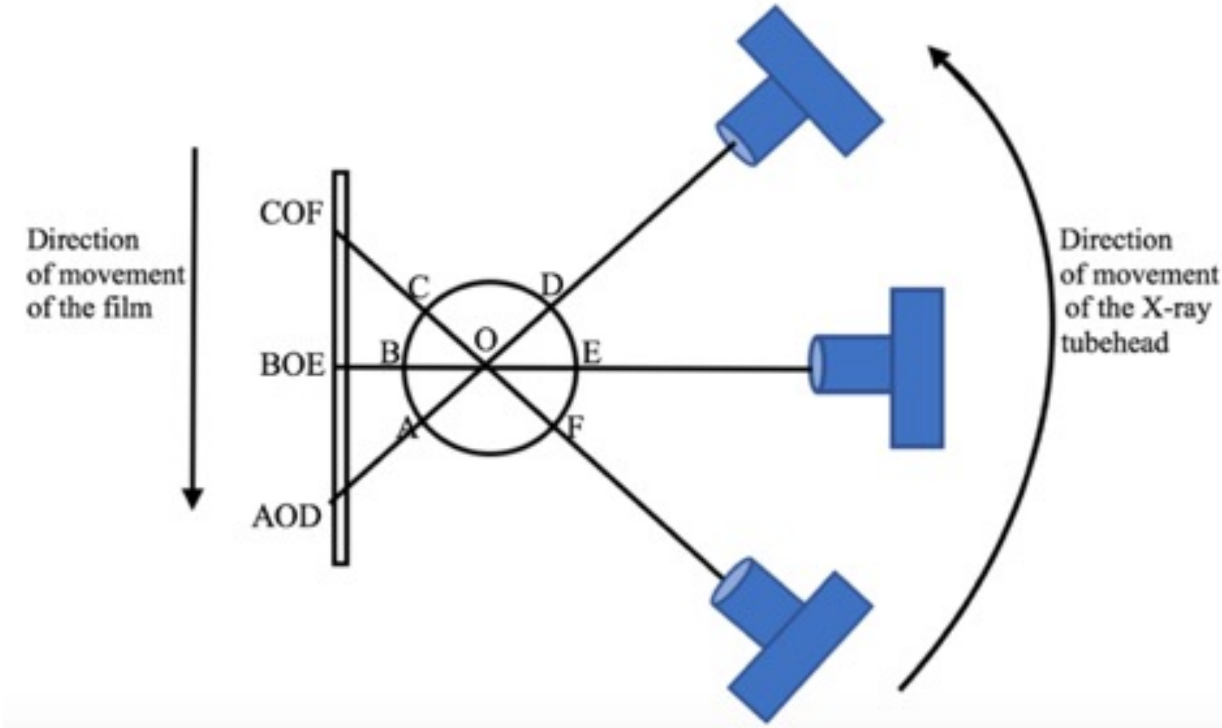

Figure 1. The principle of production of tomographic images.

The X-ray tube and the film move in opposite directions. Point O is the center of rotation and is projected on the same area of the film, thus appearing well defined. On the other hand, points A, B, C, D, E and F will be out of focus and appear blurred.

In Figure 1, only point O appears in focus as the beam is narrow. In order to produce multiple points in the area in focus, a broader X-ray beam should be used (Figure 2). Each X-ray within the beam will have its own center of rotation, forming a section that will be sharply defined in the resultant radiograph (Figure 2) (Langland et al., 1989; Vivian E Rushton & Rout, 2006).

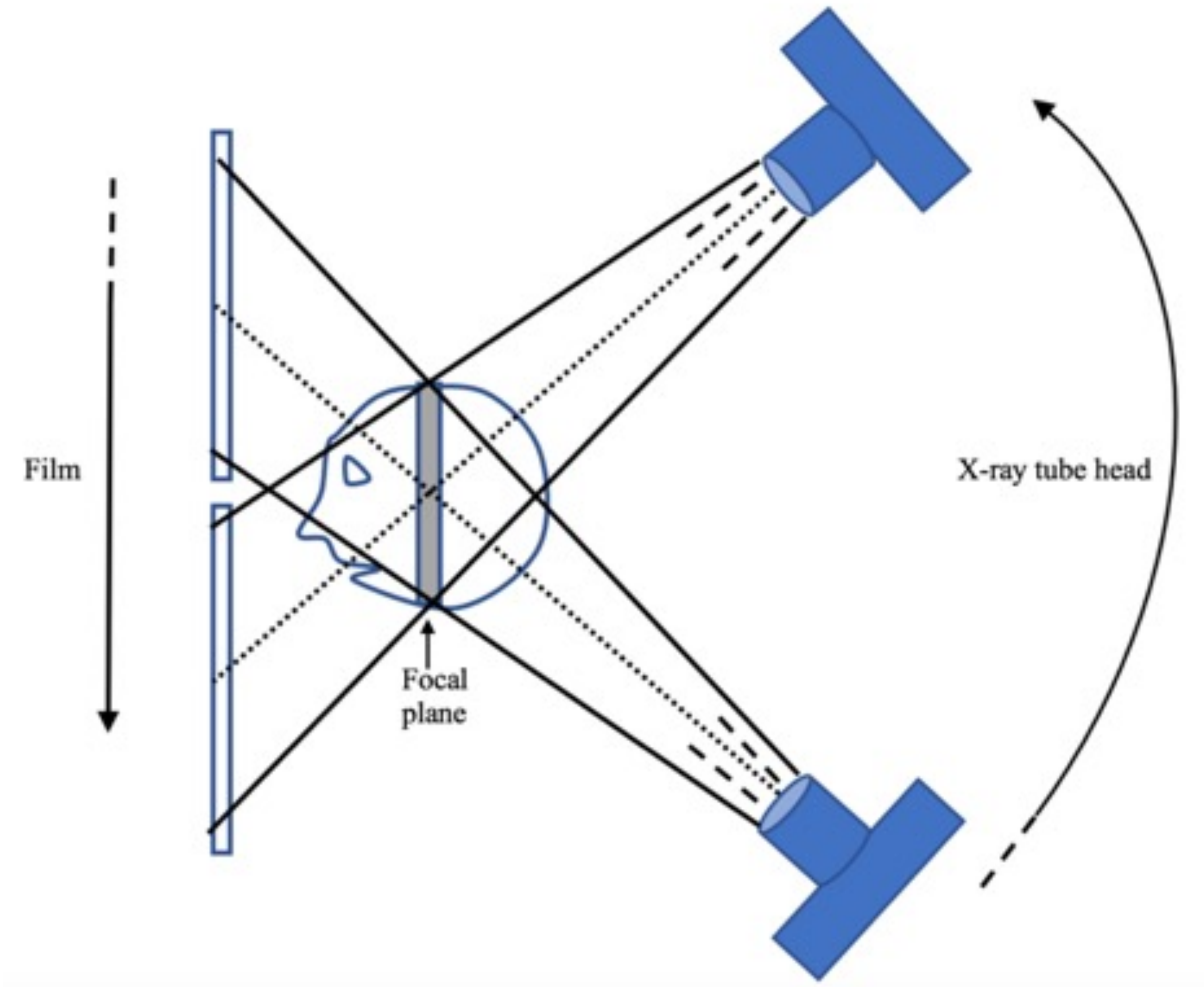

Figure 2. Broad beam linear tomography.

Movement of the film and tube head produces an image. The structures located within the focal plane will be sharply defined, while the structures outside the focal plane will appear blurred.

The thickness of the focal layer is inversely proportional to the amount of rotation of the X-ray tube. The more the X-ray tube rotates, the thinner the focal layer is, and vice versa (Figure 3) (Langland et al., 1989; Vivian E Rushton & Rout, 2006).

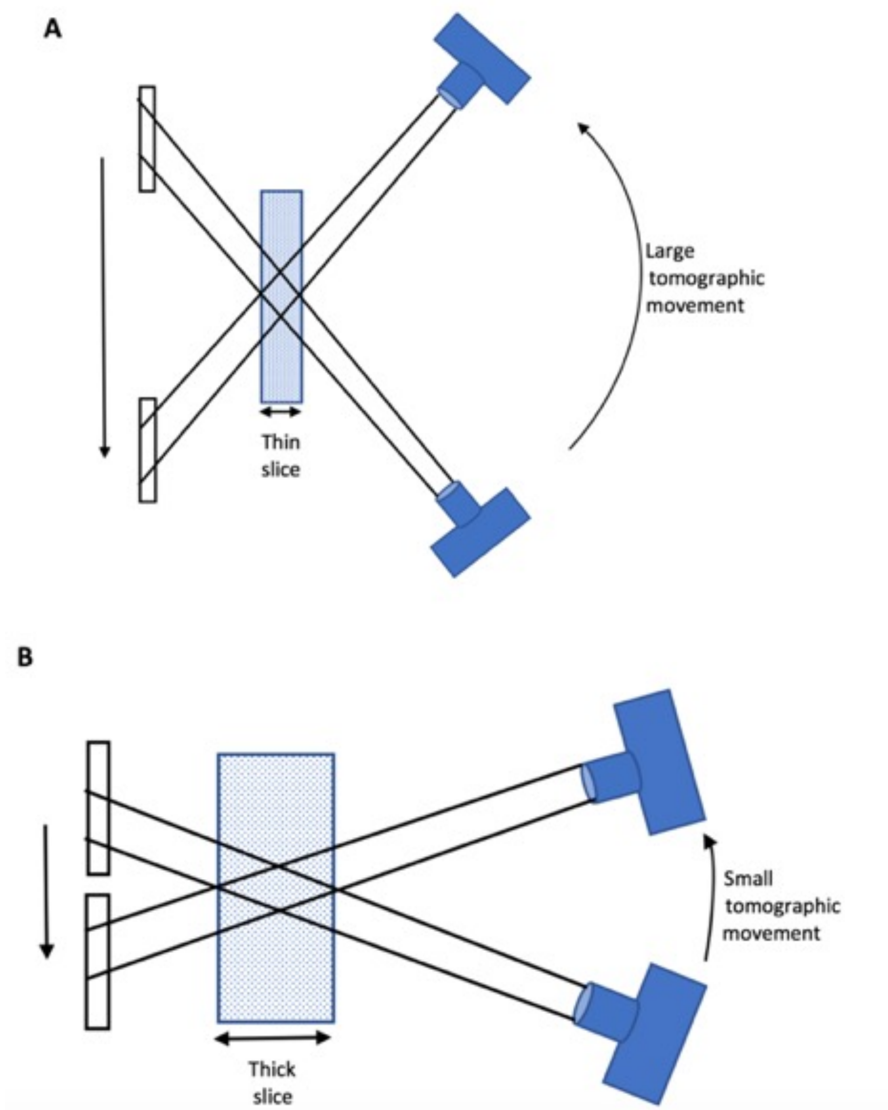

Figure 3. Thickness of the focal plane.

Thin focal slice is associated with the large magnitude of movement of the X-ray tube (A), while thick focal slice is associated with small magnitude of movement (B).

While tomography produces an image of a flat plane, panoramic radiography produces an image of a curved plane, corresponding to the shape of the dental arch. In order for the focal area to follow the form of dental arch more than one center of rotation is necessary (Vivian E Rushton & Rout, 2006). The X-ray beam exits the tube at an approximately 8-degree angle aiming upward and passes through the collimator, which is a lead plate that has a narrow vertical opening in its center (Leach et al., 2001). The collimator narrows the X-ray beam, producing parallel radiation rays. The X-ray beam passes through a section of an object and it forms a projection of that section on a film (Figure 4) (Leach et al., 2001). As the unit rotates, different parts of the patient are imaged at different stages in the cycle. Therefore, the final image is a gradual buildup of multiple projections that are integrated into one image (Perschbacher, 2012).

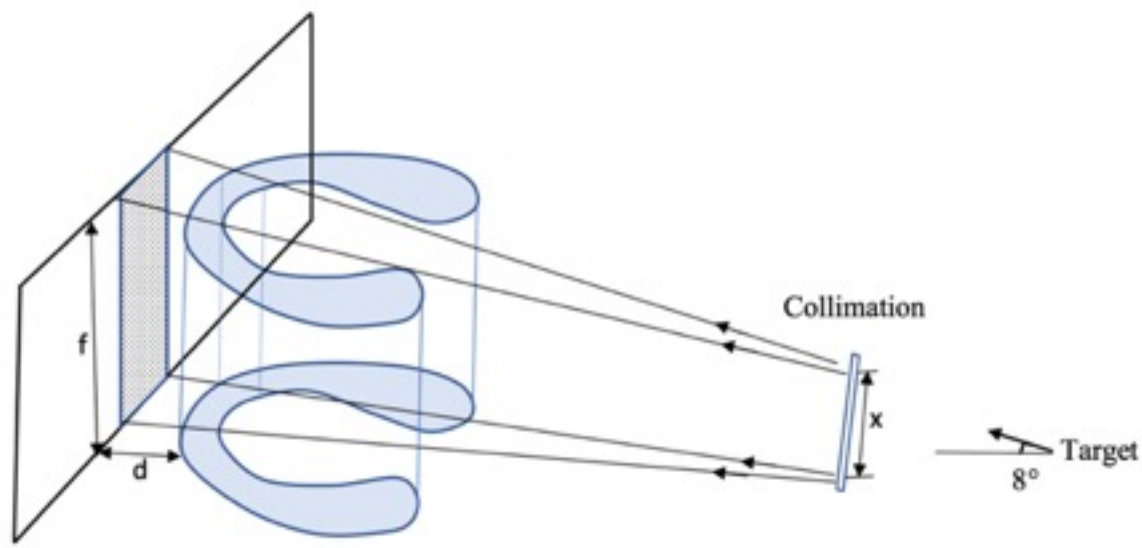

Figure 4. The main principle of panoramic radiography.

The X-ray beam (X) passes through the collimator, where it is narrowed to approximately match the height of the film (f). Note the curved zone in front of the film, within which the structures will appear in focus. A small distance (d) is always present between the film and the object located in the focal trough.

2.2 **Focal Trough**

The focal trough is a three-dimensional curved zone that has the same shape as a dental arch, resembling a horseshoe (Figure 5) (Leach et al., 2001; Ramakrishna Pawar & Makdissi, 2014). Objects that are within the focal trough will be reasonably well defined. Objects that are outside of the focal trough are blurred, magnified/reduced, or distorted. The shape of the focal trough is pre-determined and varies between different machines. Most of the time the shape of the focal trough is narrow in the area of anterior teeth and wide in the area of posterior teeth (Friedland, 1998; Ramakrishna Pawar & Makdissi, 2014).

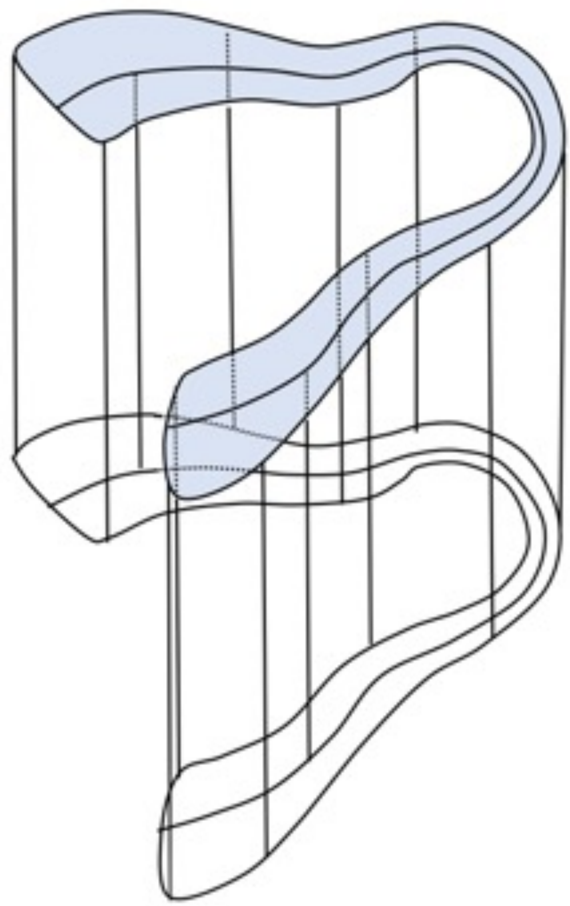

Figure 5. Focal trough.

The focal trough is a three-dimensional area, resembling a horseshoe shape, within which structures appear well defined on a panoramic radiograph.

Lund and Manson-Hing (1975) compared the focal troughs of three different panoramic machines and concluded that all focal troughs were able to encompass the entire dentition given that the patient was correctly positioned in the panoramic machine. Leach et al. (2001) also stressed the importance of correct patient positioning in the panoramic machine in order to ensure that all teeth and supporting structures appear in focus. Rushton et al. (1999) found that 33% of panoramic radiographs were lacking in diagnostic quality and one of the reasons was patient positioning errors.

2.3 **Magnification and Distortion**

Magnification and distortion are inherent qualities of panoramic radiography (Friedland, 1998). Magnification refers to proportional enlargement of an object (Gage & Picket, 2008), while distortion is disproportional enlargement, where some parts of the object are magnified more than others, resulting in a change of object's apparent shape (Friedland, 1998).

It has been found that magnification of panoramic radiographs can be up to 20% (Sameshima & Asgarifar, 2001), versus less than 5% in periapical radiographs (T. A. Larheim & Eggen, 1979). Magnification may vary between panoramic radiographs taken using different machines, and also between different regions of the same radiograph (Abdinian et al., 2016; Thanyakarn et al., 1992). Magnification has been found to be symmetrical between right and left sides of panoramic radiographs (Yeo, Freer, & Brockhurst, 2002).

Magnification in the vertical axis is dependent upon the X-ray source and object-to-film distance. The farther away the object is located from the film and the closer the X-ray source is, the larger the magnification will be. Horizontal axis magnification depends upon the center of rotation and its relative position to the object (Langland et al., 1989). It has been found that horizontal magnification is non-uniform, causing distortion of an object in the horizontal axis, while in the vertical axis magnification has a more uniform pattern (Yeo et al., 2002). This is beneficial for root resorption studies since the vertical axis is the most important axis when measuring changes in root length.

2.4 **Methods of Measuring Root Resorption**

Different methods have been proposed to radiographically assess root resorption. Some authors use ordinal scales. Levander and Malmgren (1988) divided root forms into five categories: normal, short, blunt, dilacerated, pipette-shaped. Sharpe et al. (1987) used the following scale: “0 = no apical root resorption, 1 = slight blunting of the root apex, 2 = moderate blunting at the root apex up to one fourth of the root length, 3 = excessive blunting of the root apex beyond one fourth of the root length”.

The other method to measure root resorption uses ratio scales, i.e. performing measurements with calipers or some computer aided device. Maribella and Artun (1995) measured root resorption by simply subtracting post-treatment radiographic tooth length from pre-treatment radiographic tooth length. Other authors attempted to use correction factors to calculate the adjusted post-treatment tooth length in order to account for magnification. For example, Linge and Linge (1991) used the ratio between before-treatment (C1) and after-treatment (C2) crown length measurements as a correction factor: C1/C2. McFadden et al. (1989) used the mean (CX) of the pretreatment (C1) and posttreatment (C2) crown length as a correction factor: CX= (C1+C2)/2. Brezniak et al. (2004) compared the three aforementioned methods and found that the most accurate was the Linge and Linge method using the median cementoenamel junction (CEJ) point (the midpoint between the mesial and distal CEJ points). It was also concluded that simple subtraction of post- and pre-treatment tooth length cannot serve as an accurate method due to changes in tooth angulations at pre- and post-treatment time points. Katona (2006) also studied the compensatory algorithms suggested by Linge and Linge and McFadden et al. and concluded that those algorithms cannot give reliable results even in perfectly delineated, idealized teeth with well-defined landmark points. Furthermore, clinical characterizations of natural teeth and issues of landmark definition clearly demonstrates flaws in root resorption assessment (Katona, 2006).

2.5 CBCT in Measuring Root Resorption

Orientation errors, as well as magnification and distortion inherent to panoramic radiography, can be overcome by using cone beam computed tomography (CBCT), an alternative radiographic technique that allows visualization of multiple two-dimensional (2-D) views in all three dimensions of space (H. Lund, Gröndahl, & Gröndahl, 2010; H. Lund, Gröndahl, Hansen, & Gröndahl, 2012; Sherrard, Rossouw, Benson, Carrillo, & Buschang, 2010). The principle of this technique is based on a cone shaped X-ray beam that circles around the patient's head with the center of rotation located in the midpoint of the head, the jaws, or at the specific point of interest (Sethi et al., 2016).

During the exposure, multiple 2-D data sets are collected and combined into a volumetric projection. Data can be visualized as 2-D images in axial, coronal, and sagittal planes of space, as well as a volume rendering projection, which gives a clinician a perception of the three-dimensional (3-D) image (Sethi et al., 2016).

Multiple studies have shown CBCT measurements to be highly accurate (Dudic, Giannopoulou, Leuzinger, & Kiliaridis, 2009; H. Lund et al., 2010, 2012; Sethi et al., 2016;

Sherrard et al., 2010; Topkara, Karaman, & Kau, 2012). Lund et al. (2010) concluded that CBCT can accurately and precisely assess root shortening. They found that the mean difference between direct physical measurements of root length on dry skulls and root length measured on the corresponding radiographs to be 0.05 mm (Lund et al., 2010). Sherrard et al. (2010) also reported a high accuracy of CBCT with no statistically significant differences between actual teeth measurements and CBCT measurements. Moreover, CBCT can detect surface type root resorption or slanted resorption, otherwise undetectable on panoramic and periapical radiographs. Slanted resorption was found to be a relatively common phenomenon, affecting the palatal surface of up to 15% of upper central and 11% of upper lateral incisors (Lund et al., 2012). Thus, CBCT can be a promising radiographic technique for evaluation of root resorption.

3. MATERIALS AND METHODS

3.1 Design and Sample

The sample of the current study consisted of twenty-four dry skulls. Digital panoramic radiographs and a cone beam computed tomograph (CBCT) were taken on each skull. Panoramic radiographs were taken for each skull under 7 different skull positions in the panoramic machine. Crown and root measurements were made on panoramic radiographs for all teeth except third molars. CBCT radiographs were taken for one skull positon and only incisors and canines were measured. Crown/root ratios of teeth were calculated and compared between panoramic radiographs with respect to the skull's position in the panoramic machine. Additionally, crown/root ratios of incisors and canines were compared between 0° panoramic radiographs and CBCT scans.

The research sample was obtained from the University of Illinois at Chicago College of Dentistry. Thirty-four dry skulls were initially available. Ten skulls were excluded from the sample after applying the exclusion criteria (Table 1). A total of one hundred sixty-eight panoramic radiographs and twenty-four CBCT images were produced. Some of the panoramic radiographs were excluded from the sample after applying the exclusion criteria (Table 1). The final sample size consisted of one hundred twenty panoramic radiographs (five for each skull) and twenty-four CBCT scans. A total number of 440 teeth were included in the study, consisting of the following teeth groups: upper incisors – 49, lower incisors – 26, upper canines – 32, lower canines – 29, upper premolars – 67, lower premolars – 81, upper molars – 70, lower molars – 86 teeth (169 roots). The number of measured roots was higher than the total number of teeth due to measuring both mesial and distal roots on mandibular molars.

3.2 Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were applied as described in the table below (Table I).

TABLE I

INCLUSION AND EXCLUSION CRITERIA

	Inclusion criteria	Exclusion criteria
Skull	✓ Skulls of adolescents and adults with a complete or almost complete permanent dentition	✓ Skulls of children or adolescents with deciduous or mixed dentition ✓ Skulls with multiple missing or broken teeth
Teeth	✓ Teeth from second molar to second molar with clearly visible reference points	✓ Reference points were not clearly visible: ➢ Significant crown damage ➢ Extensive caries or restorations ✓ Third molars if present
Panoramic Radiographs	✓ Good quality panoramic radiographs with most of the teeth clearly visible	✓ Teeth were severely overlapped or out of the focal trough ✓ Hard palate superimposed on the roots of the upper incisors ✓ Roots significantly deviated or not fully developed

Skulls of adolescents and adults with a complete or almost complete permanent dentition were included in the study. Skulls of children or adolescents with deciduous or mixed dentition were excluded. Additionally, skulls were excluded if most of the teeth were broken or missing.

Individual teeth were excluded if:

- Reference points were not clearly visible, either due to tooth structure imperfections (significant chip of the crown or incisal edge, extensive caries or restorations, considerable attrition or abrasion) or due to panoramic image imperfections (teeth were out of the focal trough, hard palate was superimposed on the roots of the upper incisors, or teeth were severely overlapped);
- Roots were significantly deviated or not fully developed;
- Third molars were excluded if present.

All +15° and -15° panoramic radiographs were excluded from the study due to most of the teeth being significantly overlapped or out of the focal trough, or because the view was obstructed by superimposition of other anatomical structures.

3.3 Radiographic Technique

Each skull was exposed to seven panoramic radiographs and one CBCT scan. For all radiographs, the skull was positioned by the primary investigator as described below.

3.3.1 **Panoramic Radiograph Technique**

First, the skull's jaws were slightly dis-occluded with wax and the lower jaw was moved slightly forward to allow the central incisors to bite on the bite stick (Figure 6). Red utility wax was placed occlusally between upper and lower molars. The skull was positioned in the panoramic machine (Orthopantomograph ® OP300-1 D, Instrumentarium Dental Inc., Tuusula, Finland) at 0°, +5°, +10°, +15°, -5°, -10°, -15°, where 0° was the position at which Frankfort Horizontal (FH) was parallel to the floor. The number was positive when the head was tilted up, and negative when the head was tilted down in relation to FH. The skull was positioned so that the vertical laser orientation line passed through Nasion (Na) at the internasal suture and the anterior nasal spine (ANS). At 0° the horizontal laser line coincided with FH. To angulate the skull in 5° increments, a printed degree caliper was used (Figure 6). The settings for exposure were as follows: 66 kV, 8 mA, 16 s. Examples of the resultant panoramic radiographs under ideal head position (Figure 7) and under upward/downward head tilt (Figure 8) are presented below.

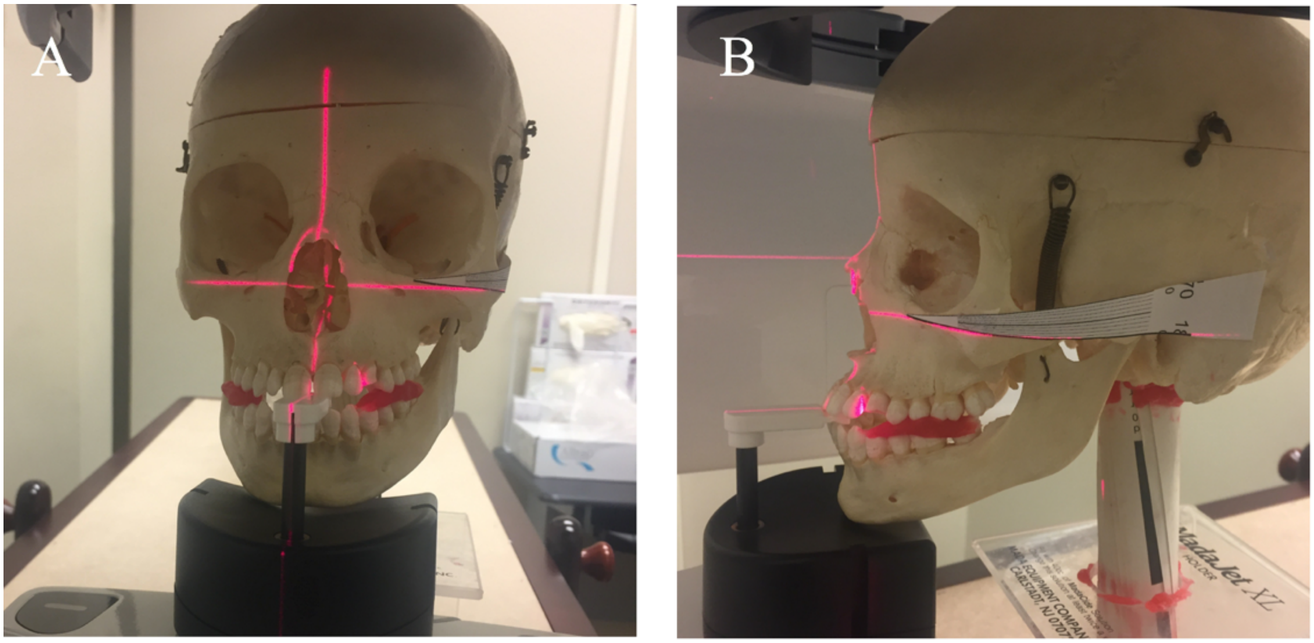

Figure 6. Skull’s position in the panoramic machine at 0°.

Skull is positioned biting on the bite stick, with the red utility wax placed occlusally to support the lower jaw. (A) The vertical laser line passes through Nasion - ANS. (B) The horizontal laser line passes through FH (Porion – Orbitale).

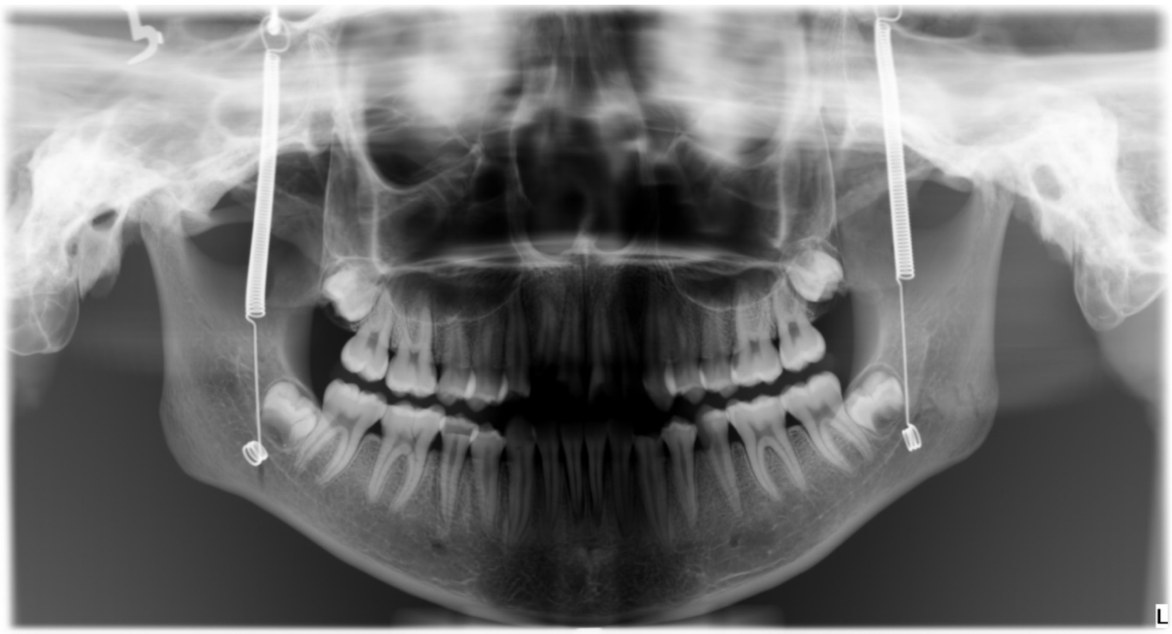

Figure 7. Panoramic radiograph at 0° head position.

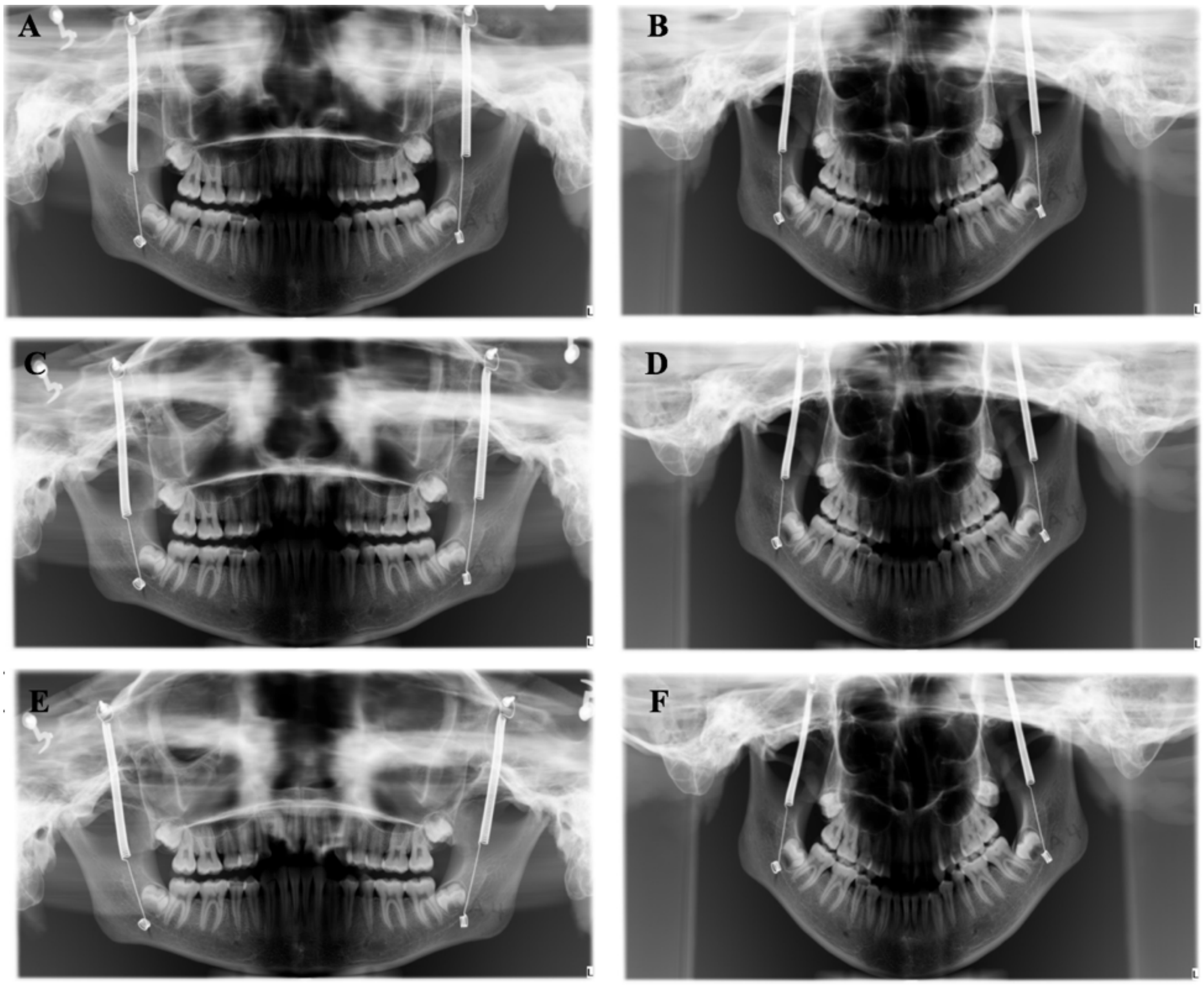

Figure 8. Panoramic radiographs at tilted head positions.

On the left-hand side panoramic radiographs with upward head tilt are represented, taken at +5° (A), +10° (C) and +15° (E). Note tipped up occlusal plane. On the right-hand side panoramic radiographs with downward head tilt are represented, taken at -5° (B), -10° (D), -15° (F). Note tipped down occlusal plane.

3.3.2 <u>**CBCT Radiograph Technique**</u>

To obtain CBCT images, the I-CAT 17-19 (Images Sciences International LLC, Hatfield, PA) was used. The acquisition protocol was as follows: 120 kV, 5 mAs, 4 s exposure time. Voxel size was 0.3 mm, and field of view (FOV) was 13 cm for all scans. The skull was positioned with

FH parallel to the floor and the vertical laser orientation line passing through Na and ANS. The chin was positioned in the chin holder. The jaws were dis-occluded with wax using the same method as stated previously for the panoramic radiographic technique.

3.4 **Measurement Technique**

All teeth were measured on the panoramic radiographs, excluding third molars. Incisors and canines were measured on the CBCT scans. For each tooth, two reference lines were digitally placed. The vertical reference line was drawn from the root apex to the cusp tip or the visually determined mid-point of the incisal edge. The horizontal reference line was drawn connecting mesial and distal CEJ points (Figure 9). The crown height and root length were measured along the vertical reference line from the cusp tip or incisal edge and the root apex respectively to the point of intersection with the horizontal reference line (Figure 9).

For multi-rooted teeth, the following roots were measured: upper pre-molars, buccal root; upper molars, mesio-buccal root; lower molars, mesial and distal roots. For teeth with multiple cusps the highest cusp tip, corresponding to the measured root, was selected. Careful consideration was given to select the same cusp tip in all compared radiographs (Figure 9).

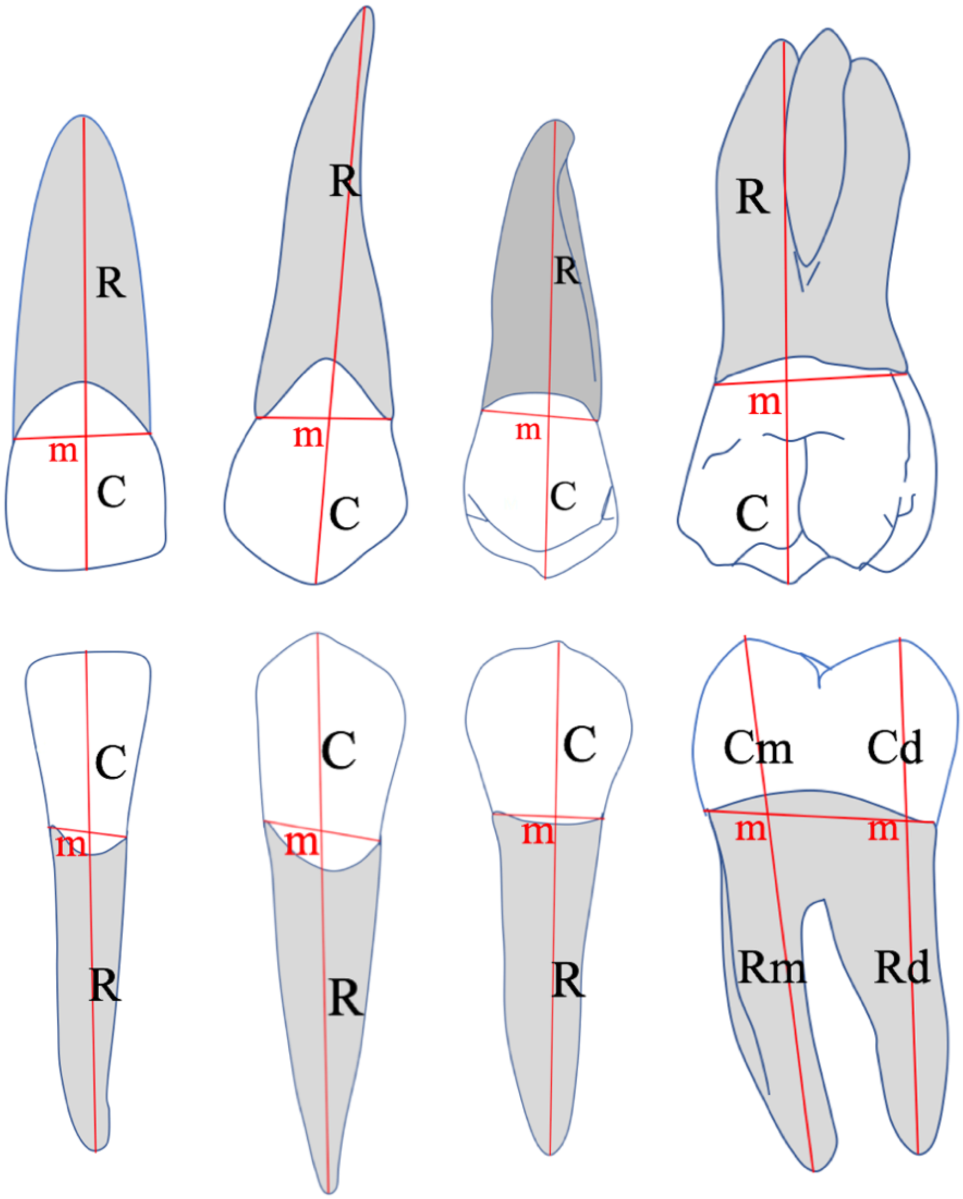

Figure 9. Graphic representation of reference lines.

Vertical and horizontal reference lines were placed on each tooth. Point **m** refers to the point of intersection between the two reference lines and divides the tooth for crown (**C**) and root (**R**) segments. For lower molars, both roots were measured. **Cm** and **Rm** refers to the mesial segments, **Cd** and **Rd** refers to the distal segments of crown and corresponding root respectively.

3.4.1 <u>**Panoramic Radiograph Measurement Technique**</u>

Panoramic radiographs were exported from Dexis® software (Dental Imaging Technologies, Version 10.1.2.70) as JPEG files and imported into Adobe© Photoshop® CC (Version 14.2.1X32). Image resolution for all files was 96 pixels per inch. All measurements were performed on a Dell 30" LED monitor (U3014) with a screen resolution of 2560 X 1600 PPI.

Panoramic Images were enhanced in Photoshop® for better visualization by applying the following features (Figure 10):

- High Pass Filter (Filter-Other-High Pass, Radius 5.0; Linear Light Blending Mode): This filter was used to sharpen the image for better visualization of the desired structures.
- Invert: This function was useful for better visualization of root apices.
- Change of Contrast: This function was applied when better visualization of incisal edges was needed.

Using the line tool, the horizontal and vertical lines were drawn for each tooth. Using the ruler tool, crown and root segments of the tooth were measured in pixels. Drawing the reference lines was done at 100% image magnification level. Measuring the lines was done at 300% magnification level.

Measurements of crowns and roots were recorded in Excel® (Microsoft Excel for Mac, Version 15.40). C/R ratios were calculated in percentages by dividing the crown height by the root length, multiplied by 100%.

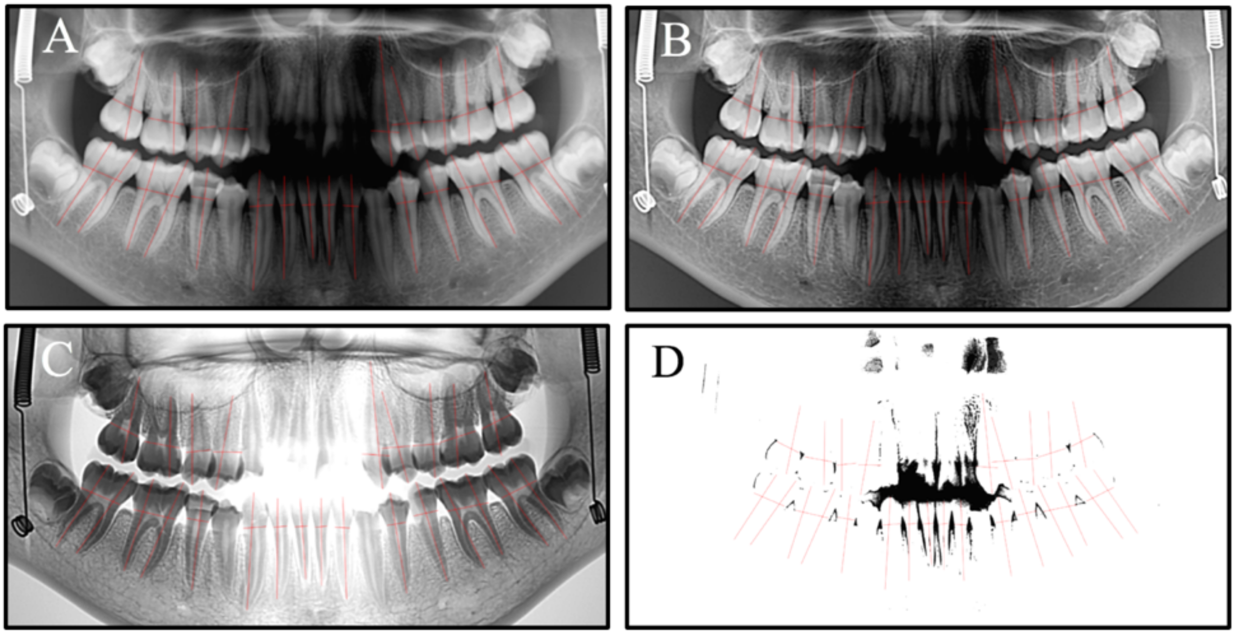

Figure 10. Image enhancement in Photoshop®.

A – Original image, B – Image was sharpened by application of High Pass filter, C – Invert function was applied for better visualization of roots, D – Change of contrast was applied for better visualization of incisal edges/cusp tips of incisors and canines.

3.4.2 **CBCT Radiograph Measurement Technique**

CBCT scans were imported into Dolphin 3D® software (Dolphin Imaging Systems, Chatsworth, California, Version 11.9 Premium) as DICOM files. The scans were then oriented for each measured tooth with respect to all three planes of space: sagittal, axial and coronal.

First, the axial slice was positioned at the level of mesial and distal CEJ, perpendicular to the long axis of the tooth. Viewed from the axial slice, the coronal slice was oriented through the middle of the tooth mesio-distally and the sagittal slice was oriented through the middle of the tooth bucco-lingually. Viewed form the coronal slice, the sagittal slice was oriented along the long axis of the tooth through the root apex and the midpoint of the incisal edge/cusp tip. Viewed from the sagittal slice, the coronal slice was oriented along the long axis of the tooth through the root tip and the incisal edge/cusp tip. All three planes were perpendicular to each other (Figure 11).

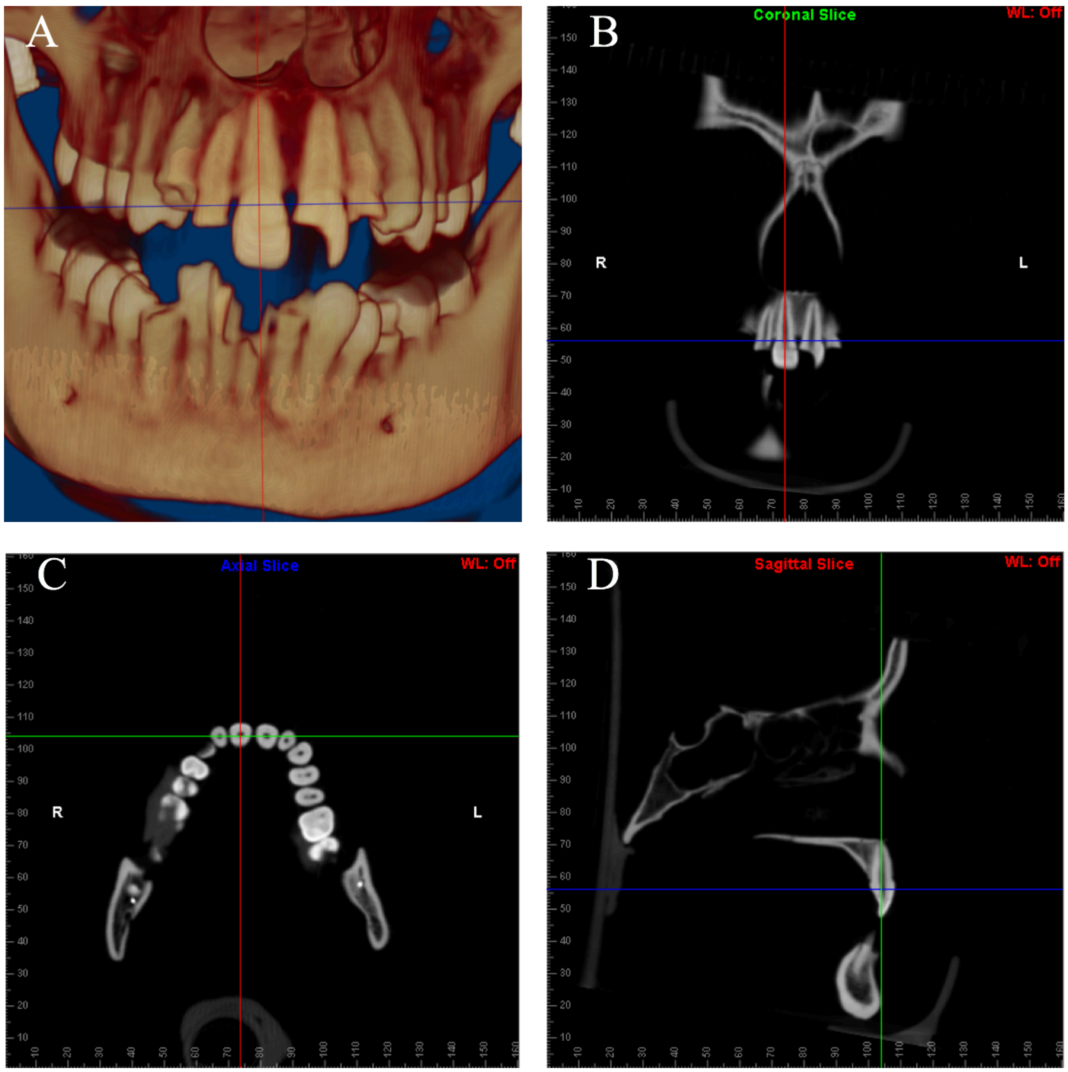

Figure 11. CBCT image orientation.

(A) 3D volume rendered image was used for visualization of all three planes of space. Coronal (B), axial (C), and sagittal (D) slices were properly orientated for each tooth.

The crown height and root length were then measured on the coronal slice along the sagittal slice line passing vertically through the root tip and the midpoint of the incisal edge/cusp tip. A reference line was drawn through the mesial and distal CEJ points to divide the tooth into crown and root portions. Crown and root measurements were recorded in millimeters and crown/root ratio was calculated in percentages using an Excel® spreadsheet (Figure 12).

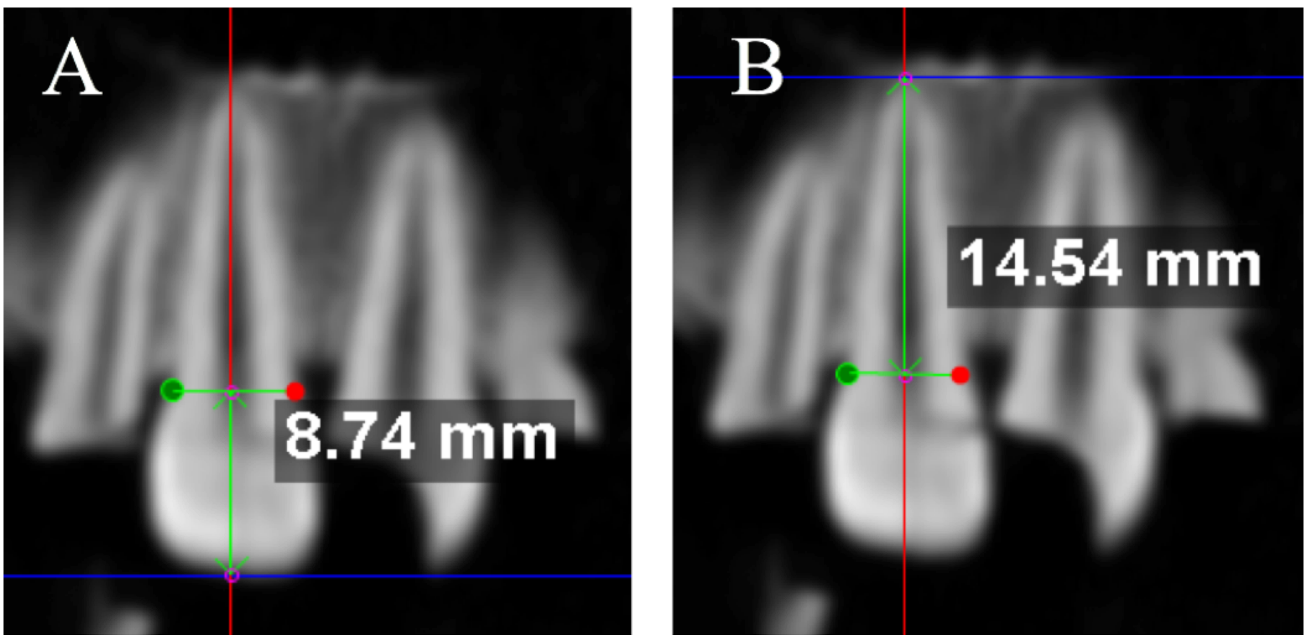

Figure 12. Crown (A) and root (B) measurements performed on CBCT.

The measurements were done along the red sagittal slice line passing vertically along the long axis of the tooth, through the root apex and the mid-point of the incisal edge. The horizontal reference line was placed passing through the mesial and distal CEJ points, dividing the tooth into crown and root portions.

3.5 Reliability Testing

Reliability testing was performed for the panoramic and CBCT radiographs measuring techniques.

3.5.1 Panoramic Radiographs Reliability

To assess intra-examiner reliability of the panoramic radiograph measurements, upper and lower molars on five randomly selected 0° panoramic radiographs were measured by the same investigator twice at a 4-week interval.

To assess inter-examiner reliability of the panoramic radiograph measurements, the same radiographs were measured by another investigator after reading the instructions of the method.

3.5.2 CBCT Radiographs Reliability

Only intra-examiner reliability was assessed by measuring 5 teeth of each of the following groups: upper incisors, lower incisors, upper canines, lower canines. Measurements were done twice by the same investigator at a 2-week interval.

3.6 Data Analysis

For the purpose of statistical analysis, all the teeth were divided into 8 groups:

- Group 1 – Upper Incisors
- Group 2 – Upper Canines
- Group 3 – Upper Premolars
- Group 4 – Upper Molars (mesio-buccal root)

- Group 5 - Lower Incisors
- Group 6 – Lower Canines
- Group 7 – Lower Premolars
- Group 8 – Lower Molars (mesial and distal roots)

Panoramic radiographs of different orientations were compared with each other. Assumption of normality of the data was evaluated using a Shapiro-Wilks test. The majority of the variables were shown to have a normal distribution. Parametric and non-parametric tests were used according to the variable raw data distribution.

Paired student t-tests were used to compare the mean differences of the crown/root ratios of incisors and canines between 0° panoramic radiographs and CBCT scans.

A repeated measures analysis of variance (ANOVA) was conducted to assess whether there were differences in the crown/root ratio measurements among five different degrees of panoramic radiograph angulations. A paired student t-test was applied for the mean comparison of the pair of degrees measurements when needed.

Statistical significance was set at 0.05. The data analysis was performed with IBM SPSS Statistics® for Windows (Version 22.0, IBM Corp., Armonk NY).

4. RESULTS

4.1 **Reliability**

The intra-class correlation coefficient (ICC) was determined for each variable as an indicator of consistency in the study method for the variables measured for the intra- and inter-examiner reliability. The correlation coefficient for all teeth groups was higher than 0.80 (p-value<0.05), indicating a good degree of intra- and inter-examiner reliability.

4.2 **Panoramic Radiographs vs CBCT**

The majority of the variables were shown to have a normal distribution. Parametric and corresponding non-parametric tests were quantitatively similar. The presented report is using parametric tests results (Tables II, III and IV).

Paired Student t-tests showed that there were statistically significant mean differences in crown/root ratio measurements between 0° panoramic radiographs and CBCT scans in the group of upper incisors and canines. However, there were no statistically significant mean differences in crown/root ratio measurements between 0° panoramic radiographs and CBCT scans in the group of lower incisors and canines (p-values > 0.05) (Table II).

TABLE II

TEST RESULTS ON CROWN/ROOT RATIO MEASUREMENTS OF INCISORS AND CANINES BETWEEN 0° PANORAMIC RADIOGRAPHS AND CBCT SCANS

Teeth group	Radiograph	N	Mean	Std. Deviation	Mean Difference	95% Confidence Interval		P-value
						Lower	Upper	
Maxillary incisors	0° panoramic	49	44.8035	12.46508	-1.46653	-2.88404	-.04902	0.043
	CBCT	49	46.2700	11.59463				
Maxillary canines	0° panoramic	32	37.8268	10.17445	1.57841	.03419	3.12263	0.045
	CBCT	32	36.2483	8.68498				
Mandibular incisors	0° panoramic	26	44.0029	7.65048	0.52183	-1.13518	2.17884	0.523
	CBCT	26	43.4811	6.21834				
Mandibular canines	0° panoramic	29	34.0648	9.38046	0.15863	-2.04174	2.35899	0.884
	CBCT	29	33.9061	10.18067				

4.3 **Angulated Panoramic Radiographs vs 0° Panoramic Radiographs**

Repeated measures analysis of variance (ANOVA) indicated that there were statistically significant differences in crown/root ratio measurements in all of the teeth groups except lower incisors. Paired t-test results and descriptive statistics for all groups of teeth is presented in Tables III and IV.

TABLE III

TEST RESULTS AND DESCRIPTIVE STATISTICS OUTPUT FOR UPPER TEETH (%)

Descriptive Statistics / Paired Variables	Mean Difference	Std. Deviation	95% Confidence Interval of the Mean Difference		P-value
			Lower	Upper	
Upper Incisors					
Pair 1 (0°; +5°)	1.99679	4.73693	.63618	3.35739	.005
Pair 2 (0°; -5°)	-.01277	4.41178	-1.27998	1.25444	.984
Pair 3 (0°; +10°)	2.07100	6.00520	.34611	3.79590	.020
Pair 4 (0°; -10°)	-.34427	4.31866	-1.58473	.89620	.579
Pair 5 (+5°; -5°)	-2.00956	5.14982	-3.48876	-.53036	.009
Pair 6 (+5°; +10°)	.07422	5.88388	-1.61583	1.76426	.930
Pair 7 (+5°; -10°)	-2.34105	6.02639	-4.07204	-.61007	.009
Pair 8 (-5°; +10°)	2.08378	6.98803	.07658	4.09097	.042
Pair 9 (-5°; -10°)	-.33150	4.95794	-1.75558	1.09259	.642
Pair 10 (+10°; -10°)	-2.41527	6.77218	-4.36047	-.47008	.016
Upper Canines					
Pair 1 (0°; +5°)	.45706	2.95592	-.60866	1.52278	.388
Pair 2 (0°; -5°)	-.04966	3.00606	-1.13347	1.03414	.926
Pair 3 (0°; +10°)	3.41216	3.78204	2.04859	4.77573	.000
Pair 4 (0°; -10°)	.79019	3.92770	-.62589	2.20628	.264
Pair 5 (+5°; -5°)	-.50672	2.33612	-1.34898	.33554	.229
Pair 6 (+5°; +10°)	2.95510	4.03070	1.50188	4.40832	.000

TABLE III (continued)

TEST RESULTS AND DESCRIPTIVE STATISTICS OUTPUT FOR UPPER TEETH (%)

Descriptive Statistics / Paired Variables	Mean Difference	Std. Deviation	95% Confidence Interval of the Mean Difference		P-value
			Lower	Upper	
Upper Canines					
Pair 7 (+5°; -10°)	.33313	4.26034	-1.20288	1.86915	.661
Pair 8 (-5°; +10°)	3.46183	4.47532	1.84830	5.07535	.000
Pair 9 (-5°; -10°)	.83986	3.37520	-.37703	2.05675	.169
Pair 10 (+10°; -10°)	-2.62197	5.38956	-4.56511	-.67883	.000
Upper Premolars					
Pair 1 (0°; +5°)	1.44120	4.39448	.36930	2.51309	.009
Pair 2 (0°; -5°)	-.30890	4.46262	-1.39742	.77962	.573
Pair 3 (0°; +10°)	4.21531	4.26299	3.17549	5.25514	.000
Pair 4 (0°; -10°)	-.64757	4.79321	-1.81673	.52158	.273
Pair 5 (+5°; -5°)	-1.75010	4.50936	-2.85002	-.65018	.002
Pair 6 (+5°; +10°)	2.77411	5.17324	1.51226	4.03597	.000
Pair 7 (+5°; -10°)	-2.08877	5.43267	-3.41390	-.76364	.002
Pair 8 (-5°; +10°)	4.52421	5.88375	3.08905	5.95937	.000
Pair 9 (-5°; -10°)	-.33867	5.22763	-1.61379	.93645	.598
Pair 10 (+10°; -10°)	-4.86288	5.91487	-6.30564	-3.42013	.000

TABLE III (continued).

TEST RESULTS AND DESCRIPTIVE STATISTICS OUTPUT FOR UPPER TEETH (%).

Descriptive Statistics / Paired Variables	Mean Difference	Std. Deviation	95% Confidence Interval of the Mean Difference		P-value
			Lower	Upper	
Upper molars					
Pair 1 (0°; +5°)	2.11076	4.23519	1.10831	3.11321	.000
Pair 2 (0°; -5°)	-2.58973	5.29436	-3.84288	-1.33657	.000
Pair 3 (0°; +10°)	4.83034	5.36765	3.55984	6.10084	.000
Pair 4 (0°; -10°)	-3.63177	5.71641	-4.98482	-2.27872	.000
Pair 5 (+5°; -5°)	-4.70049	6.06096	-6.13510	-3.26588	.000
Pair 6 (+5°; +10°)	2.71958	4.69699	1.60782	3.83134	.000
Pair 7 (+5°; -10°)	-5.74253	7.19484	-7.44553	-4.03954	.000
Pair 8 (-5°; +10°)	7.42007	7.12097	5.73456	9.10557	.000
Pair 9 (-5°; -10°)	-1.04204	6.19336	-2.50799	.42390	.161
Pair 10 (+10°; -10°)	-8.46211	7.89189	-10.33009	-6.59413	.000

TABLE IV

TEST RESULTS AND DESCRIPTIVE STATISTICS OUTPUT FOR LOWER TEETH (%)

Descriptive Statistics / Paired Variables	Mean Difference	Std. Deviation	95% Confidence Interval of the Mean Difference		P-value
			Lower	Upper	
Lower canines					
Pair 1 (0°; +5°)	-1.25298	3.62192	-2.63068	.12472	.073
Pair 2 (0°; -5°)	-.16277	3.94835	-1.66464	1.33911	.826
Pair 3 (0°; +10°)	-1.39768	3.76156	-2.82850	.03314	.055
Pair 4 (0°; -10°)	1.19319	3.90599	-.29257	2.67894	.111
Pair 5 (+5°; -5°)	1.09021	3.95155	-.41288	2.59330	.149
Pair 6 (+5°; +10°)	-.14470	3.85522	-1.61115	1.32175	.841
Pair 7 (+5°; -10°)	2.44616	4.16708	.86109	4.03124	.004
Pair 8 (-5°; +10°)	-1.23491	4.41606	-2.91470	.44487	.143
Pair 9 (-5°; -10°)	1.35595	3.91060	-.13156	2.84347	.072
Pair 10 (+10°; -10°)	2.59087	4.75990	.78030	4.40144	.007
Lower premolars					
Pair 1 (0°; +5°)	-.22306	3.34243	-.96213	.51602	.550
Pair 2 (0°; -5°)	.79792	3.76783	-.03521	1.63106	.060
Pair 3 (0°; +10°)	-1.94912	3.84253	-2.79878	-1.09947	.000
Pair 4 (0°; -10°)	.87736	4.23848	-.05984	1.81457	.066
Pair 5 (+5°; -5°)	1.02098	4.61012	.00160	2.04036	.050
Pair 6 (+5°; +10°)	-1.72607	4.28115	-2.67271	-.77943	.001

TABLE IV (continued)

TEST RESULTS AND DESCRIPTIVE STATISTICS OUTPUT FOR LOWER TEETH (%)

Descriptive Statistics / Paired Variables	Mean Difference	Std. Deviation	95% Confidence Interval of the Mean Difference		P-value
			Lower	Upper	
Lower premolars					
Pair 7 (+5°; -10°)	1.10042	5.01827	-.00921	2.21005	.052
Pair 8 (-5°; +10°)	-2.74705	4.82255	-3.81340	-1.68070	.000
Pair 9 (-5°; -10°)	.07944	4.40164	-.89385	1.05272	.871
Pair 10 (+10°; -10°)	2.82648	5.36821	1.63948	4.01349	.000
Lower molars					
Pair 1 (0°; +5°)	.24254	3.79508	-.33378	.81886	.407
Pair 2 (0°; -5°)	-.40194	4.09877	-1.02438	.22050	.204
Pair 3 (0°; +10°)	.86812	4.38146	.20275	1.53349	.011
Pair 4 (0°; -10°)	-1.67060	4.62979	-2.37368	-.96752	.000
Pair 5 (+5°; -5°)	-.64448	5.07098	-1.41456	.12561	.100
Pair 6 (+5°; +10°)	.62558	4.92999	-.12309	1.37425	.101
Pair 7 (+5°; -10°)	-1.91314	5.69218	-2.77756	-1.04872	.000
Pair 8 (-5°; +10°)	1.27006	5.59692	.42011	2.12001	.004
Pair 9 (-5°; -10°)	-1.26866	4.34781	-1.92892	-.60840	.000
Pair 10 (+10°; -10°)	-2.53872	6.03577	-3.45532	-1.62213	.000

Pairwise comparisons were made and suggested that the majority of the mean differences in crown/root ratio measurements across tooth types were between 0° and +10°; +10° and -10°; -10° and +5°; +10° and -5° degrees (Table III, Table IV).

There were no statistically significant mean differences in crown/root ratio measurements in the group of lower incisors in any degree pair (p-values > 0.05). On the other hand, upper molars showed statistically significant difference in crown/root ratio in all degree pairs, except for -5° and -10° (Table III).

In the degree pair -10° and +10°, all teeth groups except lower incisors showed a statistically significant difference in crown/root ratio measurements (Table III, Table IV). In the degree pair -10° and +5°, all teeth except lower incisors and upper canines showed a statistically significant difference in crown/root ratio measurements (Table III, Table IV). In the degree pair -5° and +10°, all teeth except lower incisors and lower canines showed a statistically significant difference in crown/root ratio measurements (Table III, Table IV). In the degree pair 0° and +10°, all teeth except lower incisors and lower canines showed a statistically significant difference in crown/root ratio measurements (Table III, Table IV).

In the degree pairs 0° and -5°, -5° and -10°, only upper and lower molars showed statistically significant differences in crown/root ratio measurements respectively (Table III, Table IV). In the degree pair 0° and -10°, both upper and lower molars showed a statistically significant difference in crown/root ratio measurements (Table III, Table IV). Graphic illustration of the results is presented below (Figure 13).

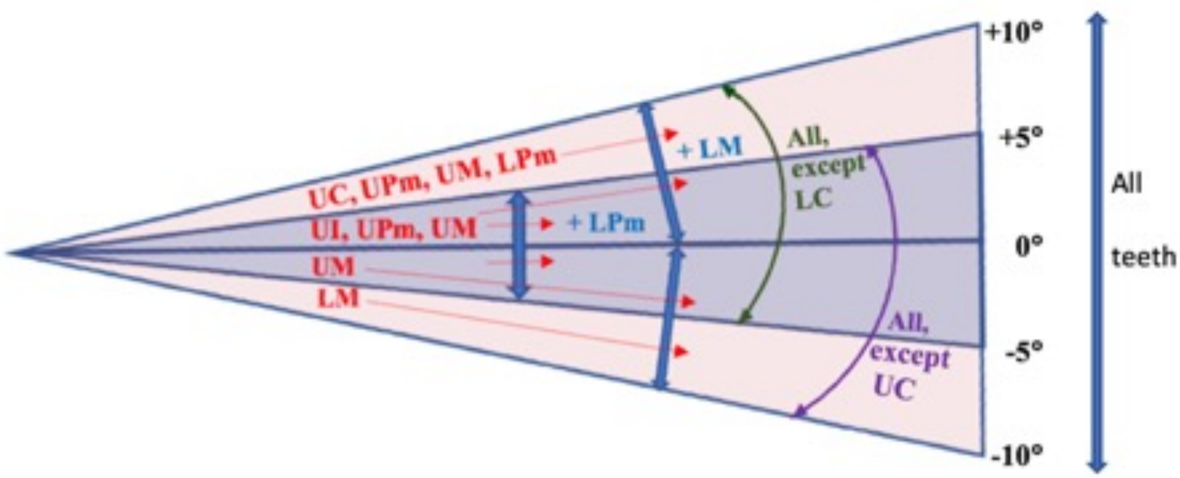

Figure 13. Groups of teeth that showed statistically significant difference in crown/root ratio measurements in different degree pairs.

Lower incisors did not show statistically significant differences in any of the degree pairs, and thus were not represented in this diagram. Teeth are abbreviated as follows: UI – upper incisors, UC – upper canines, UPm – upper premolars, UM – upper molars, LC – lower canines, LPm – lower premolars, LM – lower molars. Red arrows represent that the same teeth that showed significance in 5° pair difference, also showed significance in 10° pair difference.

5. DISCUSSION

5.1 0° Panoramic Radiographs vs CBCT

Magnification and distortion inherent to panoramic radiography are widely recognized in the literature (Abdinian et al., 2016; Devlin & Yuan, 2013; Friedland, 1998; T. A. Larheim & Svanaes, 1986; Leach et al., 2001; Sameshima & Asgarifar, 2001; Welander, Shiojima, McDavid, & Tronje, 1990; Yeo et al., 2002), thus making absolute measurements performed on panoramic radiographs inaccurate (Brezniak et al., 2004). Our study intended to test the measurement method of using crown/root ratios instead of absolute measurements.

The first aim of the current study was to compare crown/root ratio measurements of incisors and canines performed on 0° panoramic radiographs with crown/root ratio measurements obtained from CBCT scans. Upon this comparison, a statistically significant difference was found between the groups of upper incisors and canines. no statistically significant difference was found between the groups of lower incisors and canines. CBCT was our “gold standard”, as CBCT measurements have been shown to be highly reliable and almost as accurate as direct physical measurements (H. Lund et al., 2010; Sherrard et al., 2010). Only incisors and canines were compared in this study due to the complexity in performing CBCT measurements on premolars and molars in the same way as performed on panoramic radiographs, as reference points were not in the same plane of space. No statistically significant difference in crown/root ratio measurements of lower incisors and canines between panoramic radiographs and CBCT scans was found, which supports the assumption that magnification factor is relatively constant in the vertical axis in some areas of panoramic radiographs (Sämfors & Welander, 1974; Yeo et al., 2002). Although the panoramic radiograph magnifies the image by up to 20% (T. A. Larheim & Svanaes, 1986;

Sameshima & Asgarifar, 2001), our study suggests that crown and root portions of the teeth in the lower anterior area are magnified by the same amount, thus their ratio stays the same as those measured from the CBCT. The differences in the groups of upper incisors and canines suggest the presence of distortion in that area of panoramic radiographs.

5.2 Angulated Panoramic Radiographs vs 0° Panoramic Radiographs

The second aim of our study was to assess the effect of vertical head tilt in the panoramic machine on the reliability of the crown/root measurements. It has been shown in the literature that incorrect patient positioning can move the teeth out of the focal trough, causing blurring and distortion of structures (Brezden & Brooks, 1987; Dhillon et al., 2012; Jayasuriya Seena Patabedige Nileema, 2016; Khator, Motwani, & Choudhary, 2017; Kim et al., 2014; Mckee et al., 2001; Rondon, Pereira, & do Nascimento, 2014; V. E. Rushton et al., 1999).

Brezden and Brooks (1987) evaluated the quality of 500 panoramic radiographs taken in private dental offices and found that only 1 radiograph out of 500 had no technical errors present. Positioning mistakes accounted for 467 radiographs, among which 50 radiographs had the occlusal plane tipped up and 27 radiographs had the occlusal plane tipped down. On 227 radiographs, anterior teeth appeared blurred (Brezden & Brooks, 1987). Other authors also reported a high number of positioning errors affecting up to 90% of evaluated radiographs (Dhillon et al., 2012; Jayasuriya Seena Patabedige Nileema, 2016; Khator et al., 2017).

Larheim et al. (1984; 1986) studied the reproducibility of linear and angular measurements of panoramic radiography upon repeated exposures of the same subject by the same and different practitioners, thus investigating possible effect of positioning errors. The variability of the measurements caused by repositioning the patient in the machine was small between different tooth groups and between the right and left sides (Larheim et al., 1984). Larheim and Svanaes (1986) also found the horizontal variables to be less reliable than vertical ones. Although the authors assessed the possible effect of patient positioning on the reproducibility of measurements performed on panoramic radiographs, the degree of deviation in head tilt occurring upon repeated positions was not quantified. In addition, a small sample size was used, thus the results have to be treated with caution.

McKee et al. (2001) investigated the effect of head positioning in the panoramic machine on mesiodistal tooth angulations. The authors used typodonts with plastic teeth mounted in the skull's head. The skull was then exposed to panoramic radiographs at ideal head position and at 5° up/down and right/left rotations. The authors explained the decision to choose 5° angulations as an attempt to be as clinically relevant as possible, implying that this degree of inclination would likely represent the upper limit of improper patient positioning by a practitioner (Mckee et al., 2001). Xie et al. (1996) also registered skulls at 5° up/down head tilt to evaluate the tilt's influence on measurements in the vertical axis performed on panoramic radiographs. Yeo et al. (2002) studied the distortion of panoramic radiographs using an acrylic platform with test rods, which were angulated 5° and 10° mesio-distally and bucco-palatally. Higher degrees of up to 20° were also investigated in the literature (Kim et al., 2014). Although multiple studies report the frequency of positioning errors, none of the studies to our knowledge investigated the mean degree variations clinicians make when positioning the patient in the panoramic unit.

In our study, we also used 5° increments to angulate the skull to be consistent with the literature. We additionally included 10° and 15° upward and downward. At 15° angulations, we noticed that most of the teeth were severely distorted and out of focus, thus those radiographs were excluded from the study. We concur with Mckee et al. (Mckee et al., 2001) that a head tilt of 5° seems to be most clinically relevant, although we also investigated higher degrees of tilt. In practice, the risk of making severe mistakes in patient positioning tends to be low; rather a number of smaller errors in different directions take place (Sadat-Khonsari, Fenske, Behfar, & Bauss, 2012).

The results of our study indicate that changes in upward/downward head tilt caused statistically significant changes in crown/root ratio measurements of most of the teeth. Only lower incisor measurements were shown to be highly reliable despite changes in the head position, with no statistically significant differences in crown/root ratio measurements for any degree pair of angulated radiographs. Our finding conflicts with Sameshima and Asgarifar (2001), who stated that lower incisors are likely to get distorted to the extent of compromising evaluation of root resorption in that segment. The authors compared total tooth length measurements made on panoramic and periapical radiographs. The possible explanation given by the authors for distortion in lower anterior region seen in panoramic radiographs was that asking the patient to bite forward on the bite block exaggerated the lower incisor malposition in relation to occlusal plane. However, the authors calculated root resorption as the difference between pretreatment total tooth length minus post-treatment total tooth length (Sameshima & Asgarifar, 2001). As was mentioned previously, this type of measurement method is the least reliable in assessment of root resorption (Brezniak et al., 2004). Even if the measurements are adjusted for an enlargement factor of 20%, changes in tooth angulations either due to treatment effects or variations in head positioning would affect radiographic tooth length.

While in the current study lower incisors showed good degree of reliability, the upper incisors are of greater interest, as they are reported in the literature as the most frequently resorbed teeth (Blake et al., 1995; Feller et al., 2016; Ousehal et al., 2012). We found that upper incisors are sensitive to 5° and 10° upward head tilt, while not being sensitive to 5° and 10° downward head tilt. This may be explained by distortions occurring due to possible movement of the roots of upper incisors outside the narrow focal trough in the anterior area as the head is tilted up. It is hard to explain though, why the roots of lower incisors did not distort, when the head was tilted down. Possibly, it can be associated with inclination of the roots of the upper and lower incisors in relation to FH.

There have been many cephalometric norms proposed in the literature based on the studies of "ideal" faces and occlusions (Casko & Shepherd, 1984; Downs, 1948; Hellman, 1939; McNamara & Ellis, 1988; Peck & Peck, 1970; R. A. Riedel, 1950; Richard A. Riedel, 1957; Steiner, 1953; Tweed, 1954). According to the work of McNamara and Ellis (1988), the mean angulation of the upper incisors to FH in a sample of Caucasians with ideal facial features and Class I occlusion was 113° for males and 115° for females, and the mean angulation of the lower incisors to FH (FMIA – Frankfort Mandibular Incisor Angle) was 66° for males and 62° for females. Ideal patient alignment in the panoramic machine is when FH is parallel to the floor. Obviously, with alterations in head position, the incisor inclination relative to the floor plane changes. These complex relationships between cephalometric teeth inclinations, the tilt in head position, and their relation to the focal trough image layer warrant further evaluation. In our study we did not perform cephalometric analyses on the skulls.

In general, we observed a tendency for the crown/root ratio measurement of upper teeth to be affected by upward head tilt, with most of the teeth having statistically significant differences in crown/root ratio at +10°. While in the maxillary anterior area these changes are likely due to movement of the roots outside the narrow focal trough, in the posterior regions we think the changes are most likely due to landmark identification errors. When the head is tilted up, the hard palate and maxillary sinuses are superimposed on the roots of upper teeth obscuring identification of root apices.

On the other hand, 5° and 10° downward head tilt was more forgiving for the reliability of crown/root ratio measurements with only upper and lower molars showing statistically significant differences. A possible cause for these differences could be overlap of the teeth in the posterior segments, occurring with the downward head tilt, challenging identification of mesial and distal CEJ points.

5.3 **Relation to Other Studies**

This is the first study to our knowledge that investigated the effect of head tilt on the crown/root ratio measurements of teeth. Other studies that evaluated aberrant head positioning in the panoramic unit focused on its distortive effect on mesiodistal tooth angulations. Although we do not know the correlation between mesiodistal tooth angulations and crown/root ratio measurements, we can still relate our work to those studies, observing some similar tendencies.

For example, Mckee et al. found that vertical head rotation had the greatest distortion effect on the maxillary anterior and posterior teeth, while mandibular teeth were more sensitive to right/left head rotations (Mckee et al., 2001). Although we did not investigate right/left head rotations, our findings were in the agreement with the study of Mckee et al. in regard to vertical head tilt.

Hardy et al. also observed greater changes in mesiodistal tooth angulations with superior head tilt versus an inferior head tilt (Hardy, Suri, & Stark, 2009). They observed statistically significant changes in premolars at as little as 1° upward and 2° downward head tilt. In addition, no changes were observed in mandibular anterior teeth with changes in head tilt (Hardy et al., 2009), which was consistent with the results of our study.

5.4 Application of the Results

This study showed that panoramic radiograph technique is very sensitive to correct patient positioning in the panoramic machine. Thus, careful attention should be given to aligning the patient's head with FH parallel to the floor. If slight positioning error is inevitable, it is better to err on the side of downward head tilt. If the occlusal plane on the panoramic radiograph appears too flat or has a reverse smile line, indicating that the head was tipped upward during the exposure, the evaluation of root resorption in the maxillary region should be performed with caution. We recommend using ratios instead of direct linear measurements in calculating root resorption from panoramic radiographs. In uncertain clinical situations, when root resorption is suspected, a CBCT radiograph might be helpful for confirming the diagnosis.

5.5 **Limitations of the Current Study**

The possibility that measurement error in the identification of reference points could have been responsible for some of the crown/root ratio measurements differences must be considered. Identification of mesial and distal CEJ points was challenging, especially in the posterior areas with downward head tilt, as the teeth appeared overlapped. Difficulties in CEJ point identification were previously recognized in the literature (Sameshima & Asgarifar, 2001; Sherrard et al., 2010). Overlapping and inability to locate CEJ points have been reported to account for 43% of unmeasurable cases from periapical radiography and for 97% of unmeasurable sites from panoramic radiography (Pepelassi & Diamanti-Kipioti, 1997). While there are studies that used some radiopaque markers, such as metal balls (Mckee et al., 2001) or metal wires (Hardy et al., 2009) that reduce landmark identification error, we tried to represent a real clinical situation as closely as possible.

5.6 **Future Studies**

Future studies could involve investigating a larger sample size as well as using different brands of panoramic machines. It would be interesting to evaluate the mean degree error a practitioner makes when positioning the patient in a panoramic machine. We observed statistically significant differences in crown/root ratio measurements in most of the teeth at 5° head tilt. Future studies could investigate if a smaller degree tilt has an effect on crown/root ratio measurements. Additionally, future studies could evaluate the effects of anterior-posterior inclinations of upper and lower incisors and explore any associations.

6. CONCLUSION

At ideal head position, which is when FH is parallel to the floor, there were no differences in crown/root ratio measurements in lower incisors and canines in panoramic radiographs compared to CBCT. There was a difference in the crown/root ratio measurements of upper incisors and canines.

The up/down head tilt was positively associated with differences in crown/root ratio measurements of all teeth except lower incisors. Upward head tilt seems to have more of an effect on crown/root ratio measurements, especially of the maxillary teeth, compared to downward head tilt. It is suggested that this association be considered when attempting to evaluate root resorption on panoramic radiographs and careful attention should be given to patient positioning in the panoramic unit prior to exposure.

Even when the patient is aligned correctly in the panoramic unit, distortion is still present in some areas of panoramic radiographs. Thus, in uncertain cases, additional radiographic techniques, such as CBCT, can be used.

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APPENDICES

APPENDIX A

TABLE V

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	+5° Pan	-5° Pan	+10° Pan	-10° Pan	CBCT
Group 1	47.15	39.8785425	46.2117141	38.0905022	54.181601	47.9137691
Upper	72.85	63.8497653	72.7220957	60.3823686	71.3043478	63.5714286
Incisors	37.87	39.7293973	44.4801027	35.0791717	32.4691358	44
	63.4	54.3640898	58.2846004	48.2054455	59.0143481	57.4626866
	57	56.9436698	65.2094718	52.4580682	58.2833133	64.8
	33.2361516	31.6002019	32.8015016	35.4243542	31.2900274	37.804878
	33.8951311	36.3423761	31.8387681	38.0836576	34.3599615	35.0877193
	53.6971831	58.4242424	52.3836875	52.8005035	58.5037989	57.8125
	33.7935569	32.2668482	34.5328283	38.3626522	31.1646064	42.6086957
	33.6898396	33.6329984	35.7103064	40.5924301	38.3971292	39.6946565
	36.6831683	35.9884837	32.4011572	35.4	33.0586524	40.2597403
	54.5556177	60.7533414	49.3905978	51.0774607	48.4988453	58.0645161
	34.2342342	27.093359	32.6530612	39.5510422	38.1991051	39.2156863
	55.31	49.1239455	51.5566625	55.8422939	60.0127146	55.4744526
	33.41	22.9799427	26.2166405	19.1309255	28.8577154	33.8028169
	70.78	71.0732054	65.3950954	64.8817803	67.4837779	70.0934579
	40.5594406	38.3223684	41.2594458	39.4752187	42.7141268	37.8881988
	33.6075206	31.1921611	38.9059619	28.1559046	41.5070243	31.4285714
	28.0405405	27.4820144	25.4117647	33.2680059	27.0588235	29.3413174
	50.6996771	44.582505	45.8742633	58.9602446	47.8701826	42.6666667
	38.5347985	30.4147465	31.6202712	32.3660714	28.90625	34.6153846
	30.6007509	32.1575544	33.2309582	31.1125079	29.6756384	26.6129032
	37.5232198	31.7980022	35.4239257	41.6334661	31.3835771	34.2857143
	33.56	33.9193382	35.3155973	38.8807069	39.3742621	36.9495852
	69.4	67.2652642	69.3935927	66.0545645	70.5299942	60.8391608
	53.75	47.4421109	57.7146172	44.637224	50	45.3333333
	33.47	38.1571175	40.2820356	34.0385812	39.490823	36.8421053
	62.5	59.1254753	64.6412411	51.6938519	67.9702048	66.40625
	64.42	67.9327184	68.32	59.3298671	65.5571635	70.1492537
	66.79	65.6680647	69.3811075	67.6268003	62.5691457	66.9491525
	33.7831084	29.7672115	30.976431	33.3163005	35.790544	37.5757576
	48.4708598	54.1339771	55.9622196	54.6039923	50.5570292	57.9365079
	53.5035035	46.2184874	55.3072626	51.3371788	55.338809	58.1560284
	44.5448228	37.0801034	38.2746051	34.6710526	42.9942418	45.6896552
	54.8574753	48.8068182	52.4599226	45.8505003	59.4739988	57.2519084
	41.8181818	42.5209205	38.7953037	45.7700651	40.8413206	47.8873239
	30.5212251	21.7054264	22.2274882	26.0559517	30.2564103	36.4238411
	42.3	40.7134768	46.9230769	38.699187	43.8953488	45.4545455

APPENFIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 1	52.3	42.8397319	58.7030717	48.6416559	53.686934	55.7251908
Upper	36.39	35.3316327	35.7519789	36.0051713	49.6778351	43.7956204
Incisors	51.1	47.6888388	55.3571429	36.0265634	47.5375842	47.5524476
(cont.)	45.9177765	43.1469298	46.1871282	42.5603593	44.420011	46.3087248
	47.3448496	48.8095238	47.8204294	46.1227242	46.5902233	43.6090226
	36.8622449	38.0038388	33.6487286	41.0680229	33.432304	43.2
	47.5869227	40.7518797	47.2165992	47.5373547	49.5884774	50.3355705
	38.4945212	41.8524022	31.5741166	33.0823293	36.3348416	33.5195531
	25.8977901	28.3667622	34.7527473	26.3350402	30.33241	36.8852459
	27.5471698	36.7197875	31.9293478	25.4799302	27.705031	31.3559322
	41.1201179	43.5672515	43.5665914	48.1331169	44.100895	40.5940594
Group 2	36.35	39.9909829	37.3639661	34.2909091	36.5714286	36.2790698
Upper	46.69	48.6591906	49.7784343	39.0198798	42.7437142	43.1372549
Canines	49.32	49.6650718	48.9665354	52.5951557	45.5984174	44.3786982
	47.03	49.0591398	49.7672253	44.4136657	44.4195428	42.7745665
	15.34	13.8926477	15.1315789	13.5740402	16.4413432	16.2650602
	42.3959549	40.3225806	41.9232231	35.5799373	43.7754272	38.8059701
	46.8971631	44.8997773	44	35.4545455	39.8319328	36.8715084
	38.5212418	35.3558052	35.5113636	41.1082474	33.2504146	30.2564103
	29.9656694	25.4528565	27.9469548	28.7960688	26.2603116	32
	30.887522	30.5130513	27.6578411	24.1029641	28.249497	24.4131455
	46.7301325	41.8998818	39.6492566	46.7091295	43.8619484	46.961326
	34.3395002	27.5404157	32.517049	29.3296089	37.6765537	35.7758621
	22.8038234	26.7387944	24.8303935	25.2362949	22.1473029	28.7671233
	25.3138075	22.166362	23.3285233	21.2411495	21.1186114	24.3902439
	36.9978858	36.9152971	37.7717391	31.1234617	41.8693371	33.3333333
	53.9777983	53.7037037	53.2295007	50.4534606	51.2808783	51.8518519
	21.5	26.3157895	27.7089783	22.62309	25.4155496	28.3041642
	42.23	45.8270865	45.7703927	42.8149606	44.3634597	41.25
	46.12	43.2067932	41.6453756	43.9474964	38.6409736	40.3846154
	56.13	52.7887324	56.6757493	50.5928854	62.3569794	53.5211268
	42.84	42.693566	45.1165372	34.3859649	46.3806971	35.0318471
	36.96	39.4771821	39.0434783	38.3936452	41.1922905	33.7078652
	42.5629291	40.7801418	38.6919831	34.8202685	39.3435252	35.9116022
	46.1354962	45.994345	50.4924832	41.0292072	44.5652174	41.3173653
	35.0973751	33.4450964	37.0940883	34.1315089	31.4086061	30.3964758
	47.9880137	47.008547	51.8668466	39.0317052	54.1535698	50.8379888
	29.1750503	31.3745356	30.3187803	25.1512257	30.4964539	31.8584071

APPENDIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 2	35.6846473	37.8097983	33.8235294	31.0058594	31.9382162	40.5405405
Upper	21.2906784	23.6444941	22.7412731	20.9208762	26.3186514	22.1518987
Canines	25.2380952	27.4754346	28.8298265	24.846515	24.2047532	29.6482412
(cont.)	35.4131535	29.9671892	32.3847695	29.1479821	32.3127844	35.2941176
	42.5302826	41.2460209	40.4677846	35.3953298	36.9816161	43.5294118
Group 3	58.83	59.5978062	59.2064476	52.7366021	58.996328	
Upper	50.75	49.0216272	50.252667	46.2606838	47.2008782	
Premolars	60.23	62.125	63.5220126	60.0505689	63.6190476	
	45.9024159	46.5693431	50.0246184	45.423397	57.9979879	
	52.9411765	49.5934959	46.3353414	48.2862903	53.7883169	
	46.0267006	53.7970192	42.9889299	48.989547	47.4303406	
	58.5903084	58.1605529	58.7412587	48.4353106	58.785756	
	56.1759729	52.3433089	55.0484883	55.0865801	60.6687898	
	46.1154965	44.0461475	41.8817652	39.5636064	46.4685616	
	52.7873365	42.5657895	46.395806	51.4583333	42.9200755	
	59.4883998	58.9072282	59.1245026	52.6175214	61.4595899	
	51.6518091	48.2419855	53.5294118	47.0944922	46.4492372	
	43.8872772	45.2430411	42.1096003	40.9128631	42.7918571	
	53.0738861	52.1491455	58.446712	50.5856107	55.0486618	
	55.29	59.6587447	63.0461923	48.372615	54.6612623	
	57.77	49.4148936	55.9836544	53.6878216	49.0566038	
	63.08	62.4386826	57.028405	63.3514986	61.037037	
	58.18	62.6359565	59.873817	53.7037037	63.8633377	
	59.74	54.605626	60.7416127	51.6793066	62.2343655	
	44.15	42.6049618	45.1944569	40.8987744	45.3488372	
	57.239819	46.2525667	53.6859876	43.4588702	57.0087977	
	53.1696174	47.6591268	43.1246656	46.5029365	57.918552	
	55.4038005	54.2991755	53.6480687	53.6540804	51.6797312	
	56.2636166	61.4899713	52.7851459	45.1974865	54.2998897	
	69.5734003	61.1599297	62.1958457	60.7476636	63.1855309	
	46.5148064	43.3563417	42.9708223	42.2547714	43.632287	
	41.6464891	34.3804538	38.0979178	40.931677	38.8481084	
	48.4148307	44.6764092	48.9197531	43.5500516	55.6573276	
	51.6571429	49.4071146	53.8461538	46.4088398	56.724028	
	48.1464531	46.5015211	51.3485477	43.3511934	48.2973621	
	47.2207792	51.2299465	54.7308782	45.0232078	54.764574	
	68.75	59.376909	70.4496788	59.4775213	67.6923077	
	83.29	84.8768054	85.3637902	78.0113177	77.7414075	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 3	70.51	66.6666667	67.1950379	64.8148148	69.4814815	
Upper	67.64	64.6326276	69.57638	55.4305008	61.8987342	
Premolars	53.52	53.2391048	57.9927885	50.3088153	58.6706949	
	50.28	51.992966	46.4855286	51.5096618	54.2695836	
	57.3687182	57.4706212	53.2866379	48.1012658	58.9864467	
	78.9126853	86.6836302	85.4930725	70.1845018	71.1904762	
	39.2822967	38.0288238	46.04811	45.1279528	34.9712262	
	72.5816389	63.6792453	73.4256927	59.5682614	69.8221457	
	34.8711554	32.2297567	39.6341463	31.124031	36.3362069	
	46.4519976	45.3796351	37.6192868	43.2709716	39.6866841	
	69.2733564	69.1518468	70.9809264	65.2320108	72.027972	
	25.4214729	22.1334399	24.7799296	23.3682514	23.803132	
	53.110298	56.0777958	56.6058596	43.7593237	51.9830777	
	50.524109	44.8398577	53.4268753	46.3715903	52.7091005	
	57.3	50.5847953	57.073844	49.8303167	62.4586913	
	66.31	64.7767541	64.8849797	70.4529116	62.7424749	
	53.58	52.9934795	54.351585	50	56.7894131	
	67.48	63.2113821	61.4356087	70.5923836	76.7692308	
	51.8	51.7018779	56.8127962	51.4750151	59.266055	
	63.02	61.5102639	66.692367	56.1317449	63.8217523	
	48.7	50.3607504	47.5138122	46.7704993	42.8039124	
	48.75	52.722063	53.2467532	38.1769437	55.5037857	
	51.0192525	53.6	56.7388688	51.1086475	57.1163366	
	67.5675676	58.1298392	65.4050465	60.5853051	63.1782946	
	34.1199607	38.0019589	33.3333333	37.8816794	33.7440758	
	52.7762803	58.1408141	60.7323944	54.8941042	56.6954644	
	62.3279817	58.4026622	54.5550847	59.0354445	56.4204545	
	37.707712	31.0827008	37.8673384	29.304314	39.6764581	
	40.4614519	39.4781622	44.6070461	37.5568182	40.1903755	
	47.5763016	52.9485571	56.9220863	46.0427499	56.2797013	
	23.4155598	22.2564497	28.3236994	23.4505863	24.1235392	
	48.0802292	53.3101045	55.0698239	41.8469657	58.1410256	
	47.1486762	47.1523858	48.3771252	47.0933073	53.3758639	
	60.042061	53.3643892	54.4418052	50.2899315	62.0590033	
Group 4	58.6	60.0532623	63.5494881	56.2855338	63.6039886	
Upper	59.98	62.5402966	52.5790349	50.0895522	59.7944032	
Molars	56.74	52.5627045	54.2328042	53.9307312	61.9825073	
	81.43	74.0199846	80.0650936	74.8402556	84.2235004	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 4	64.86	60.0806452	73.1487444	55.1684088	67.9141442	
Upper	59.82	60.2171137	59.079118	64.6800502	52.2277228	
Molars	58.5869005	54.7080484	65.2383503	53.3665835	63.5588403	
(cont.)	68.3908046	60.7361963	79.0529695	64.5726808	75.7575758	
	82.7973074	78.0721118	90.3633491	72.962963	86.2470862	
	92.6598264	86.799693	95.0742768	83.0996885	93.0214724	
	73.4810579	69.6192696	78.3222591	64.1812865	68.6973428	
	56.557377	46.3603819	61.9594595	45.3796351	65.368272	
	43.6919716	43.9880952	43.9090417	37.9464286	42.4742268	
	74.3459302	70.2683616	68.4073107	60.7047872	78.5332315	
	60.6981982	68.0625	68.5857322	59.039039	69.6481813	
	69.2495424	65.4557043	69.9819168	64.4754316	70.860077	
	65.67	64.6382691	66.2002946	62.8803245	68.589244	
	52.46	51.5605493	50.6138393	57.3453608	57.6025237	
	57.87	61.4963504	63.4650456	56.5521258	67.125861	
	56.69	57.0011669	48.858205	55.0901687	44.180031	
	60.59	56.4825254	60.2533172	55.4555085	66.255144	
	64.2162819	70.6151832	77.2357724	53.9934354	69.3726937	
	72.6123596	71.7171717	76.6004415	67.2740525	64.683053	
	67.8066914	59.7701149	75.3424658	55.913272	78.9554531	
	67.9090335	61.7647059	69.7585769	62.5498008	74.0442656	
	87.2783346	85.7035928	92.6389977	79.1666667	76.4522174	
	61.2165179	53.4933333	60.6229143	52.1293801	63.697479	
	78.6872587	70.6373293	70.0581395	63.326226	78.8651316	
	69.0440061	65.3705062	75.2459016	52.8301887	68.5082873	
	59.7492163	59.9462366	59.6437346	52.7859238	68.2843472	
	71.9415703	65.3325123	67.6803816	64.0992998	65.8858859	
	65.3	58.7525151	64.3669447	57.5483871	77.3212818	
	59.19	54.2225201	65.2080344	56.4276049	62.5261689	
	77.88	69.1642651	74.0990991	65.8640227	92.0540997	
	60.68	50.799508	60.9859155	52.8774543	62.7891156	
	43.59	45.1906659	52.1327014	48.482933	53.2562386	
	71.03	64.4677661	74.2038217	59.2702904	81.95242	
	61.26	52.0249221	56.042654	51.2040558	67.073955	
	68.42	68.3040936	73.6612702	74.9538462	65.7159834	
	63.1782946	62.893503	67.2067401	49.6547395	64.028314	
	54.1888298	57.8843627	66.5693431	56.9461827	66.1680912	
	43.04	40.8585056	47.6776721	34.6633416	49.0449438	
	35.3923205	34.0779221	37.6777251	35.7894737	30.6711037	
	62.372065	66.0930529	72.4002616	61.3259669	76.4935065	

APPENDIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 4	38.4297521	41.0672854	46.1142322	34.5611642	46.5094776	
Upper	41.6852679	36.0465116	49.7191011	38.6072423	41.0650282	
Molars	49.4597839	50.7434944	56.3562203	45.2944748	49.1147915	
(cont.)	49.2103601	50	55.8361775	48.4503479	52.0782396	
	68.1912682	60.7488702	67.5324675	57.4134553	73.2050333	
	58.6658725	55.9509918	66.8387097	49.7002725	69.8391421	
	77.682686	73.3944954	85.3609626	63.174404	84.6153846	
	47.67	46.8135795	43.4463277	47.6514215	50.1913265	
	59.13	64.591195	58.9285714	60.1834862	57.2867696	
	60.14	61.1930295	64.3975494	61.6065351	68.1422351	
	53.32	51.8613607	61.0267534	54.7157191	64.3243243	
	88.5	93.8087774	83.7992832	81.7027633	88.7254902	
	59.344894	61.9829284	71.5333333	59.3065693	64.4695543	
	62.1830986	61.3009198	73.3082707	60.7192254	72.2741433	
	33.2700522	30.3415061	31.2641595	30.8912739	32.4705882	
	54.4621027	59.3872229	56.6091954	55.1877785	65.5290102	
	44.2461538	47.8637771	39.1947898	48.1711097	42.380085	
	64.7878404	61.3151659	60.4738155	64.75	68.0290046	
	67.9764244	66.0489742	65.3821032	62.8970775	71.321013	
	40.3449928	43.5228332	39.6103896	43.4953363	48.2071713	
	57.199211	52.9671717	64.1496599	56.8854569	64.1770401	
	48.2226693	48.2450922	56.4905414	45.6901748	55.9974343	
	42.3529412	37.8254211	41.010101	39.047619	41.7234664	
	52.4137931	50.0563063	51.0712218	45.3688297	55.3066038	
	52.215003	45.8569807	54.8699335	45.8971554	60.1591187	
	65.1349799	60.7853982	66.9385536	55.9447983	62.5958379	
Group 5	49.06	51.2804878	58.4860558	53.362256	53.6875496	48.4352774
Lower	48.5591662	47.8204294	48.1507824	53.6726804	59.0984975	47.5806452
Incisors	44.0156965	41.4558914	38.5205862	41.7037508	44.4018405	39.0977444
	39.0826873	33.3333333	29.8880843	36.3193175	34.3420127	34.6774194
	49.7704316	43.7240233	45.2040816	42.5041186	41.1627907	50.862069
	45.9571527	46.2462462	40.3495994	47.690387	42.5129088	48.5074627
	43.64	41.026806	49.6736292	45.9082734	41.0744264	43.5979513
	43.51	42.56472	39.4501718	45.7107843	44.1289332	46.4285714
	58.61	52.8289892	55.7632399	56.7729084	46.4767616	51.9083969
	37.913486	34.2840512	37.4488404	41.5249267	34.1619318	43.3333333
	31.4993954	31.8181818	28.9818863	37.5077882	26.9851952	31.6901408
	46.6122449	51.3036165	45.2208835	46.1309524	56.181998	43
	47.695684	44.3235894	41.1437649	47.8290366	41.0488246	44.6043165

APPENDIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 5	53.9792388	53.7576168	50.9211496	50.8827238	46.1003861	46.8085106
Lower	40.6674208	42.1497585	42.9419525	47.5995316	38.4715872	40.6896552
Incisors	52.77	52.0315343	51.2288786	51.2280702	53.9494471	50.2527076
(cont.)	39.0924956	32.7301338	39.8086124	50.5190311	46.9273743	42.2764228
	36.1858191	41.2761152	42.1629021	44.0740741	42.422045	42.4242424
	43.0060817	48.5915493	50.5219207	35.7197258	36.9519833	45.1612903
	39.49	40.5588103	44.980695	50	39.4500561	42.2586521
	53.6	55.1581843	53.1050955	53.3333333	46.8497577	48.5714286
	33.69	36.2461538	28.4785436	36.6725249	27.2104181	38.6861314
	52.260274	50.3555268	54.7567175	40.2122642	49.86053	48.1481481
	27.6490066	23.9677744	30.3405573	27.3119605	32.804878	23.8993711
	49.8548621	46.3244613	50.1443001	41.0127991	52.0169851	44.9612403
	35.9046283	41.6895604	39.6081772	49.7529993	44.0789474	42.6470588
Group 6	19.9	22.3274696	19.0241498	25.1546392	20.0973236	32.6666667
Lower	43.27	39.9369417	35.2767962	41.7528579	36.5636147	34.939759
Canines	37.49	44.7582575	41.7782027	46.43026	39.9026764	49.3333333
	35.7	35.9430605	31.9767442	36.4746946	29.1025641	32.3741007
	46.6666667	47.2792608	43.902439	49.4780793	42.7455357	39.7435897
	28.3084005	32.7557295	29.933615	38.330494	32.9145729	28.5714286
	23.374613	25.0517598	23.5080436	24.9866809	26.9714286	21.4285714
	32.6273096	29.5047857	31.5936626	29.9782135	35.7481061	26.519337
	23.1536926	17.4122174	18.2655039	20.8136235	18.150174	18.2926829
	31.9058824	33.287037	29.7403234	33.9106655	30.5076142	28.742515
	37.9853095	36.0435008	41.4954338	40.9753645	37.8326996	36.2637363
	46.9008264	41.6625676	46.7934783	44.9047619	39.9020142	39.7660819
	40.2502607	42.1312284	44.3030973	43.5189518	43.1181486	42.5414365
	42.75	43.7728195	47.0704087	43.371059	38.7956565	42.6096998
	40.43	41.3299233	36.6837024	42.4986932	33.7013364	41.3580247
	26.14	24.5372819	24.8612653	28.3957219	20.1709402	20.6896552
	34.12	41.6506718	36.7445055	41.1413404	31.2106368	46.0869565
	47.67	49.236857	48.6238532	43.4806328	47.9166667	48.1481481
	18.65	19.4682289	14.8705882	22.8301887	19.4277108	20.1257862
	36.1983471	41.8766756	43.9095128	37.7133989	41.6666667	34.9112426
	48	48.4051483	41.9481982	47.2521552	42.4223602	44.8275862
	22.0622387	27.0873786	22.7032227	26.6863614	17.8095708	29.0540541
	48.8125316	53.4732634	44.1354904	40.9298086	48.2517483	56.5217391
	33.5529024	33.0003842	32.3504274	31.4242653	32.9295648	28.1553398
	28.8496377	25.5632582	29.6331138	29.5935648	31.1166253	33.9393939

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 6	21.9664269	30.4396216	24.9496982	23.0590423	25.061546	20.3821656
Lower	20.8541747	22.3358238	24.6753247	22.6928896	22.8885135	17.0854271
Canines	35.9104781	39.35	43.1899642	36.8421053	30.8966305	33.8797814
(cont.)	34.3782654	34.5931759	38.6574074	33.7901701	35.4529094	34.3195266
Group 7	46.21	41.2600663	38.2480958	47.9565442	45.9167951	
Lower	53.17	54.015544	50.6007067	49.6458467	47.5342466	
Premolars	43.08	42.9257875	50.3188406	49.6952909	46.4553314	
	55.52	55.9600705	53.7447573	60.8695652	58.3704647	
	65.54	65.3811659	59.3077643	63.4080717	67.1328671	
	39.38	40.7991588	39.3190555	43.0668842	33.5710368	
	52.5215252	47.4654378	55.3030303	53.201397	57.151552	
	55.8027661	51.0457886	51.3115803	59.2885375	50.1626545	
	43.3562992	40.4919584	44.3831494	46.0964694	45.3915823	
	59.5886267	58.8779641	55.5287009	55.4107649	57.7220077	
	53.8598575	50.440044	60.0249066	51.4176663	63.1578947	
	42.4813678	40.8214585	45.4377026	46.2214411	42.5908667	
	36.2247413	34.5463367	33.4482759	33.0206379	35.7774311	
	35.8762887	33.3980583	33.1670823	38.1505811	34.7510373	
	47.7577169	45.0194769	51.2524085	45.418552	42.2372881	
	65.9574468	60.0948509	59.6728307	71.0615281	54.4285714	
	46.1726883	47.7351916	39.488117	43.8998957	41.9589676	
	46.49	47.7374441	39.3201421	51.0606061	45.8396369	
	51.7	50.1738123	47.7201749	44.902507	46.0023866	
	44.64	51.9516218	48.7760098	51.3038549	47.2803347	
	58.81	56.4697083	57.8039216	56.9129481	58.5858586	
	38.74	42.8345627	40.3709765	38.6537481	39.6736359	
	46.67	41.2957468	44.4444444	49.5049505	47.4033149	
	49.35	54.7202797	50.4944735	54.3977591	42.3986486	
	35.11	34.4280241	31.2737127	36.6666667	35.832887	
	46.8085106	51.1871894	44.8021108	53.7882859	42.374789	
	38.845727	45.7029027	41.6423995	47.737819	41.2291169	
	26.1693548	26.4503043	22.300746	27.8470825	22.675367	
	33.3135744	37.4927114	33.4960342	37.7182771	29.6407186	
	37.9562044	38.0287474	37.3626374	34.6364018	38.7998168	
	57.0783982	60.2094241	54.8997135	56.1393489	55.0581395	
	49.7545008	54	57.9661017	51.5616728	52.9830323	
	37.5619835	36.4673485	37.035473	41.8358341	39.9154334	
	35.2524776	33.5053965	32.9460967	38.7665198	34.7969783	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 7	37.3469388	38.7063655	35.6327801	42.3603793	36.4857603	
Lower	47.6854788	44.4850701	43.071161	50.7916403	46.4031108	
Premolars	38.6466165	40.4997397	37.2664175	37.1260422	35.07109	
(cont.)	47.0677452	43.02267	49.0880667	51.1917098	49.0852065	
	41.8019026	40	41.5318231	43.5114504	49.8803828	
	58.71	54.1891892	48.7947407	53.7926675	53.7959184	
	41.81	45.5502896	42.4518201	45.6498952	38.1230117	
	57	54.2961609	54.0592784	55.0392275	49.1041805	
	44.58	46.2340672	44.3899448	47.6300578	38.7453875	
	48.08	48.9944134	41.1665732	51.9197708	40.8680947	
	43.24	47.291441	44.3200895	46.3729178	39.3617021	
	18.51	22.0450797	15.9038902	22.6809955	17.3768677	
	48.23	50.47726	46.2165308	53.3717579	46.1042765	
	42.06621	52.3017903	39.3687708	40.7325194	48.0769231	
	49.5016611	45.9912989	48.2758621	54.5571245	42.4849699	
	27.3660714	24.0066225	31.4856883	28.3002588	35.326087	
	43.8341411	48.2551799	45.8428246	50.9254066	49.8428661	
	48.3233533	48.8708743	51.2380952	51.3329552	50.4854369	
	39.6513187	41.2078153	37.3045078	44.9765258	35.2380952	
	27.9744346	26.4661654	33.0314331	32.6643251	34.6518106	
	36.3543788	37.5760649	39.132734	46.1658842	31.0041408	
	33.0316742	28.9905091	33.9719626	32.6999558	26.7060965	
	34.6599496	41.6193914	34.9801249	45.9534368	37.5076359	
	39.8678414	38.9299943	45.5696203	42.3255814	32.8515842	
	52.2309711	51.1412708	46.8644639	50.4667445	44.9077239	
	44.47	44.5850202	42.5847458	43.2835821	44.1025641	
	42.07	41.9745958	39.6237172	44.3438914	42.3700391	
	50.31	52.8783383	58.5306618	47.6409666	51.7717718	
	40.41	43.4343434	34.4620426	47.7363897	39.8966705	
	41.88	43.6181435	38.9885808	45.3850355	37.8226712	
	45	41.4910026	46.8473451	41.959799	44.6280992	
	45.84	49.4143893	44.9339207	50	46.2857143	
	44.6	46.4884696	43.704122	48.310992	48.6720554	
	37.6705653	42.3585405	31.9691863	40.0948367	42.8809789	
	48.4708598	50.5387931	46.7937608	42.8643982	42.3757853	
	25.8105263	26.2322473	26.3420724	29.5473596	25.7083333	
	48.9014438	45.4491018	47.2259811	54.9810845	46.5287049	
	31.3659359	35.6365159	30.7820995	29.0386131	34.6255507	
	46.1497038	49.4565217	48.1418919	54.1905855	45.9963877	
	48.4665936	46.4012251	44.7046301	51.1160714	43.988764	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 7	38.2212581	38.051239	38.1247236	42.8055931	40.4740201	
Lower	20.503085	19.1119691	23.5818097	22.778596	23.8450075	
Premolars	30.3059273	27.4787535	33.1521739	33.1375428	32.4392713	
(cont.)	28.8043478	26.3157895	28.6326618	30.2345416	32.2033898	
	37.7893245	38.957935	39.296957	35.9790875	36.1546499	
	46.0633947	45.9722935	48.0574774	42.3336548	43.2111513	
	54.7297297	50.2934272	46.8696152	48.4665936	50.8165829	
Group 8	62.54	58.5876721	55.9481743	54.2891422	54.3706294	
Lower	63.14	66.4252798	60.5128205	54.3037089	63.0653266	
Molars	51.3	52.1572911	54.2445275	54.7077922	61.409396	
	53.54	64.1231593	64.7255689	62.5	65.1505017	
	57.13	55.1661631	55.5284056	55.3178484	53.0461538	
	52.51	63.0666667	55.0505051	47.8448276	55.7934509	
	73.11	68.7116564	68.0837954	76.298269	64.5996388	
	57.31	55.9766764	64.648318	62.8691983	60.1276843	
	56.98	59.178744	62.0833333	64.9088542	59.6604215	
	78.9846517	76.8803946	66.8597914	78.1941032	66.2404092	
	60.1726264	62.5318066	63.2124352	56.7567568	62.6444159	
	36.101083	35.5940847	34.8477525	44.2162162	42.7909372	
	62.8109453	58.5852479	66.2239089	55.0811786	67.746114	
	67.8714859	73.0746269	72.5149701	60.2683781	71.0136337	
	64.1642229	61.8738951	64.5620023	60.8323831	69.0866511	
	48.6338798	46.8550593	50	40.5651778	54.4587506	
	62.192691	59.75212	62.0777565	57.9292267	56.9371728	
	58.6863106	51.4355528	56.1533704	50.6157635	61.6883117	
	56.4102564	53.2915361	55.4204125	45.4028926	58.6373391	
	53.8057743	49.9740798	54.3161435	46.5767635	59.6633778	
	54.6623794	62.9735936	54.4554455	51.890411	55.3733032	
	56.8922306	58.3615437	61.9286162	52.5146963	62.2036262	
	54.78	60.2477477	56.0547945	54.0782123	59.9539701	
	57.83	60.9482221	58.1931464	47.8716841	56.7342074	
	52.1	56.4490016	46.643461	50.8933129	50.6066734	
	59.89	61.4963504	62.3717949	63.9303483	62.4500666	
	53.08	61.4152203	49.2002559	52.948886	52.6933702	
	55.56	62.0558376	55.1681957	48.2820976	54.3945913	
	74.21	73.4394904	69.5231959	79.0744467	67.3064619	
	54.21	54.8260382	60.058309	58.9454976	59.8050459	
	59.94	54.2227004	56.8460309	56.4718733	59.3347639	
	59.71	58.9611872	53.171738	64.6422129	56.5027322	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 8	67.1555788	65.7282079	65.513571	73.7875289	63.9624724	
Lower	56.1066336	59.3572779	54.2630938	47.6306197	58.9937107	
Molars	40.9385921	42.8863869	37.2376769	43.0280957	40.3257651	
(cont.)	63.3747547	65.5378486	65.7122905	56.6083283	57.4541284	
	63.5911602	66.6287016	61.5690733	65.0574713	65.5844156	
	56.8722944	59.8560354	56.8627451	56.2242798	59.0251741	
	52.5243168	51.230629	53.9325843	50.0234852	53.2455315	
	68.5310387	61.5057681	66.003729	66.8387097	66.2393162	
	56.598063	51.5312132	52.1637427	51.7878427	57.6971214	
	51.3729406	50.3948667	55.977131	53.3507853	60.4257642	
	53.9927872	51.2486993	57.2133845	47.2966145	57.1832579	
	53.7305699	61.6730454	51.1099366	52.5929806	55.7493188	
	62.8983764	65.7432432	60.2620087	61.573472	70.2349869	
	70.68	70.2156334	64.5634162	66.6666667	68.6237374	
	62.26	61.9176232	57.7348066	67.3157163	54.1723666	
	46.13	45.6288776	42.1221865	45.2861035	41.0648392	
	60.51	57.8745198	59.4027954	62.1271077	63.9322917	
	55.34	55.4347826	56.0264172	58.2568807	59.2004381	
	61.32	57.3020528	60.4409063	60.5487805	60.3448276	
	65.2679148	74	65.4100529	79.1752577	78.66394	
	58.9774078	58.6080586	64.516129	56.2537403	64.3648208	
	44.9331849	43.246311	43.3761878	45.44406	47.2747497	
	66.6437414	66.6204025	66.5034965	72.9893778	72.6708075	
	48.0974125	50.751503	50.6617258	50.4567437	51.6393443	
	61.0140845	56.5290179	61.9625138	60.3903559	61.8503712	
	64.6103896	59.8021027	69.0614887	65.4289373	71.1574953	
	46.7902996	44.454671	44.2335074	46.9129801	51.7797817	
	66.8459987	70.9205021	61.7414248	67.9104478	62.1067031	
	49.4428152	45.8796026	54.3087415	46.1970075	58.2236842	
	41.0509886	45.1115834	36.9246862	41.9843342	40.1075269	
	56.4058957	56.2573099	62.2504537	55.3469852	62.3081645	
	47.2698908	45.3549061	46.2394068	49.1724506	48.2815057	
	54.2806183	49.4532199	55.9794989	45.5603184	56.4720048	
	56.79	58.0805295	51.5134838	52.0487265	49.1794311	
	64.95	65.9628919	59.2638037	61.8283322	61.7775016	
	61.14	63.2545932	59.0152566	68.6680469	62.7477785	
	54.63	56.7120047	49.8054475	53.8415724	48.8558352	
	56.67	59.2814371	50	60.498615	53.2560706	

APPENDIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 8	54.36	54.9539171	59.6973094	54.0556542	64.7402218	
Lower	65.0692841	70.5057892	71.0748792	71.9156851	57.1944612	
Molars	62.1538462	59.6978852	60.2894902	51.8667433	63.5355512	
(cont.)	47.5026567	45.1612903	45.90766	44.5887446	49.5372891	
	62.7289956	63.001975	66.8776371	62.5845737	71.9806763	
	69.4952856	59.4784353	68.0497925	58.4376565	66.4519592	
	66.3417431	64.8743425	71.0979228	63.0512515	63.0651791	
	65.3365098	60.15625	65.276212	68.1029324	69.2045455	
	49.611399	45.8947368	50.66313	47.9892761	52.9254131	
	63.6800962	62	62.0560748	63.6589919	68.1214421	
	55.2272727	52.1264368	55.7803468	51.1856564	61.5384615	
	55.154901	54.4955045	47.7756286	55.1	52.1695761	
	56.6058596	55.3107345	59.3805837	58.5549133	60.8907871	
	59.6799174	57.3271414	50.6979063	56.5608466	57.104843	
	61.030303	56.4596273	63.4638923	57.9084967	60.617284	
	56.22	57.7490775	53.9598109	57.9842137	52.6617058	
	61.81	59.7014925	64.0108035	63.3217993	66.5980796	
	61.76	52.9778786	56.9635386	58.8061466	60.1591187	
	60.78	55.6311881	67.8042498	63.8137193	64.3685567	
	44.53	47.3021583	46.2895377	44.3230115	47.8580171	
	66.67	68.115942	72.1940623	67.1213209	70.014771	
	63	56.7948718	65.9503022	70.4274702	61.7426821	
	62.57	65.9167604	69.1922006	62.9213483	64.3724696	
	58.26	58.4249084	61.6093366	61.509434	65.884591	
	63.3603239	51.7002519	62.6058632	61.0554442	68.0851064	
	57.7427822	58.2484725	59.8064516	49.6124031	66.5983607	
	44.0669371	39.1933816	48.8335101	43.8441558	43.1372549	
	59.9203716	63.1153068	65.6883298	60.4778157	57.9738562	
	48.3024691	48.5370951	50.0993049	44.1735739	54.2321338	
	54.8888889	56.5616046	52.4303659	57.1254568	62.2418879	
	66.5175719	66.9576897	65.9326425	63.3289125	73.324306	
	42.8711898	40.5811138	42.0106848	42.0172084	45.0298211	
	48.7134503	44.9913144	49.6659243	47.3309609	53.6585366	
	43.6697248	38.1530984	40.0713436	36.9422963	46.1829653	
	48.4316853	50.1128668	48.5611511	47.579758	51.2258738	
	55.0276243	63.084922	57.8503095	54.5250141	63.7847642	
	51.3136729	49.3485342	57.8272981	45.8289335	58.0206634	
	59.1364205	57.0975919	64.0471513	56.1294337	65.7480315	
	58.48	58.5201794	50.0274876	59.6230725	56.1235955	
	60.74	57.3132454	68.2037164	60.1588352	62.7187079	

APPENDIX A (continued)

TABLE V (continued)
RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 8	54.56	51.3972603	51.6057586	53.5097814	51.3165266	
Lower	63.81	60.3728202	64.5363409	60.932768	61.3333333	
Molars	48.72	52.7829894	45.2818627	48.8110138	46.2530713	
(cont.)	65.82	66.0514173	70.2142364	66.4392906	68.3060109	
	58	60.177453	58.2681273	55.723205	58.7378641	
	56.76	58.65663	59.7647059	59.3596059	58.3237658	
	58.9805825	55.2776083	56.982911	58.9041096	62.2961104	
	54.4191919	59.651388	58.8345865	52.8201725	59.6204188	
	41.0621147	41.884058	39.868049	40.1215805	44.7122479	
	55.1466001	59.025609	58.9262613	57.0483124	51.6564417	
	49.490316	46.7750127	49.1442543	45.6857855	54.4652129	
	52.2162162	55.8056872	49.3456925	54.0617849	51.4840799	
	60.238806	61.6617211	62.4923266	61.5200479	66.6060606	
	43.4115523	40.6001765	42.6318161	46.3289963	42.7780341	
	49.9143347	46.3825014	46.905016	48.5403549	46.0933403	
	44.2004505	40.9168081	41.6204218	37.2752044	44.8956571	
	51.5010352	52.2246941	52.1830615	51.5053763	51.4091858	
	57.9539067	58.496732	52.8846154	53.2596685	54.5191194	
	47.4279835	49.3950552	55.9849705	48.2581967	54.0289256	
	53.9285714	54.3373494	59.9250936	53.5185185	52.3781903	
	75.04	66.8826494	67.7852349	66.9230769	71.6801174	
	48.62	54.2207792	50.6453596	48.4924623	47.7897252	
	56.82	54.9613402	63.3858268	55.6146179	59.2239186	
	62.42	66.6666667	64.9451259	67.2657253	70.0594845	
	51.57	51.7117117	57.7164366	55.6638246	48.6785495	
	61.7942769	59.6423017	60.1688411	64.3525741	70.685384	
	60.4861111	56.3648294	55.3583169	55.5483029	61.6990641	
	44.7803765	47.6162448	42.4208773	46.4373464	37.2019078	
	64.1887062	64.3162393	70.3759398	58.2728592	66.1670236	
	41.9726027	39.2876417	42.0660277	35.5053874	38.5233551	
	56.302996	62.2988506	59.9418605	59.8599767	56.69383	
	59.6190476	59.6753247	65.1997292	63.064833	71.1681296	
	44.7932237	47.4142345	47.1782178	40.6205924	50.1806918	
	54.8348348	50.9291521	56.7583732	50.2837684	58.6124402	
	46.3598901	47.1047495	45.4306377	55.2033081	51.4043109	
	41.0229645	41.6445623	45.490982	42.6517572	51.6402116	
	56.9221628	59.7295708	61.9762351	50.6952491	61.8012422	
	51.5489467	52.0050125	49.4273659	58.4139265	53.1615925	
	52.2284997	53.3126935	55.420957	50.9657321	54.468599	

APPENDIX A (continued)

TABLE V (continued)

RAW DATA. CROWN/ROOT RATIO MEASUREMENTS (%)

	0° Pan	**+5° Pan**	**-5° Pan**	**+10° Pan**	**-10° Pan**	**CBCT**
Group 8	56.55	57.8088578	48.5142857	56.5812984	52.025463	
Lower	64.26	58.2830315	67.8519594	60.2480418	64.0915594	
Molars	55.27	58.1865623	56.2419562	54.6426186	53.4341525	
(cont.)	59.41	58.1122764	62.5	53.9386651	57.8162291	
	64.35	63.5913313	65.8393207	64.6948941	69.3820225	
	53.21	49.917988	56.5569035	54.2583192	50.4607046	
	58.4206848	56.1989101	60.3253182	56.092437	66.6914498	
	61.9688385	60.3566529	55.47898	54.855643	62.4733475	
	41.4234511	37.6055638	42.9873418	37.1801567	41.446384	
	60.5104097	64.9484536	66.7805878	59.9310345	61.1289288	
	52.3678414	48.1157837	49.7331393	54.3500512	50.9984639	
	58.2248521	59.7762073	57.7658303	63.9303483	52.1181717	
	60.2923264	56.3900666	56.9612206	58.6970272	67.5368139	
	44.4136657	44.7632058	47.7975633	43.7806509	48.8083889	
	52.1094641	50.4756575	57.7629382	49.0293955	54.5707915	
	54.36457	51.2148338	53.3501896	53.3903884	56.6437929	
	43.4782609	45.9969403	51.7063082	48.8164124	53.060166	
	51.6987542	57.0512821	55.2397869	49.4960806	51.9976838	
	58.0552359	56.4026206	53.285078	56.1130334	62.6957494	
	54.3942993	54.3839542	57.3410405	57.543232	56.825015	

APPENDIX B

PANORAMIC RADIOGRAPHS

SKULL 1

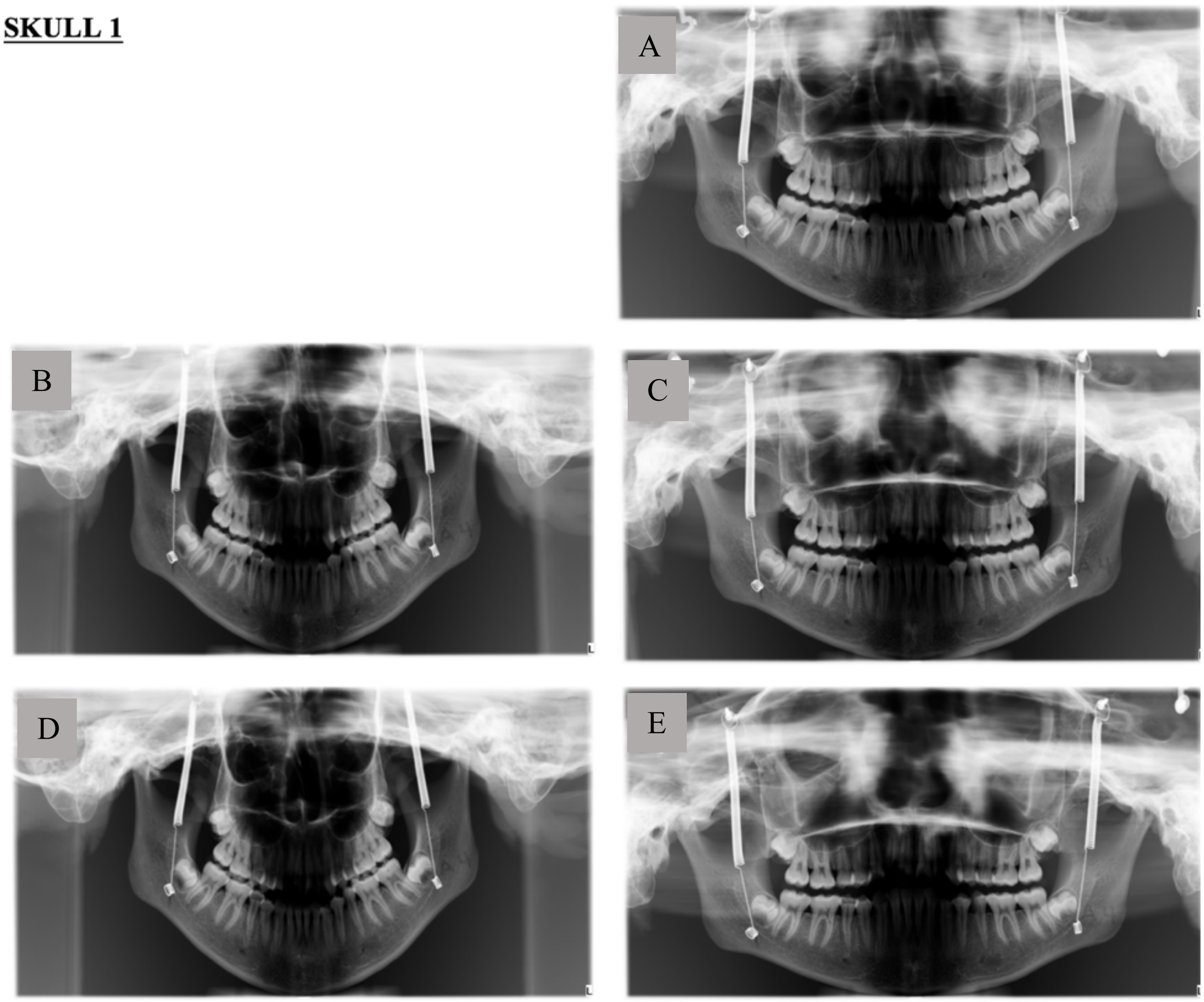

Figure 14. Skull 1.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

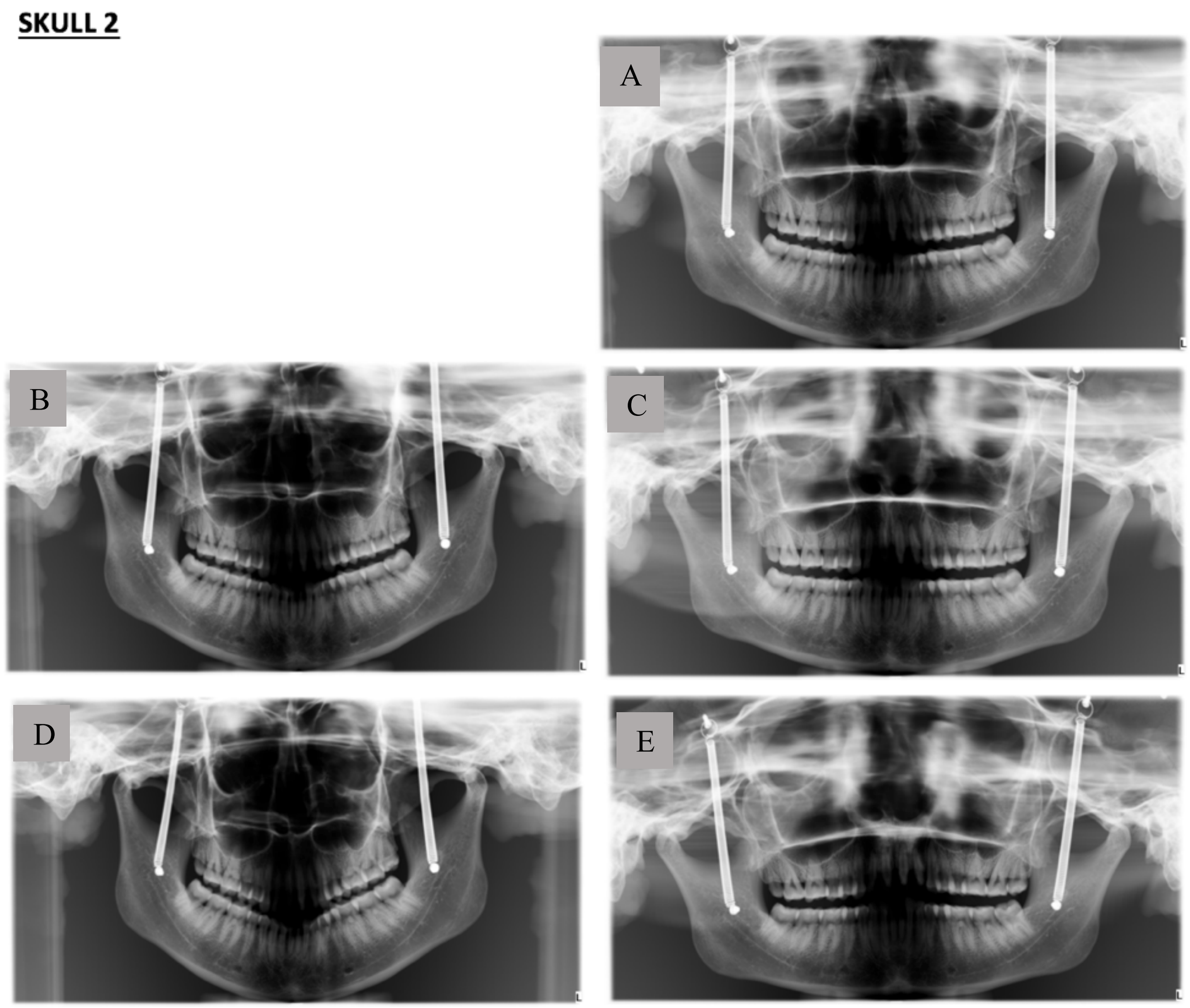

Figure 15. Skull 2.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 3

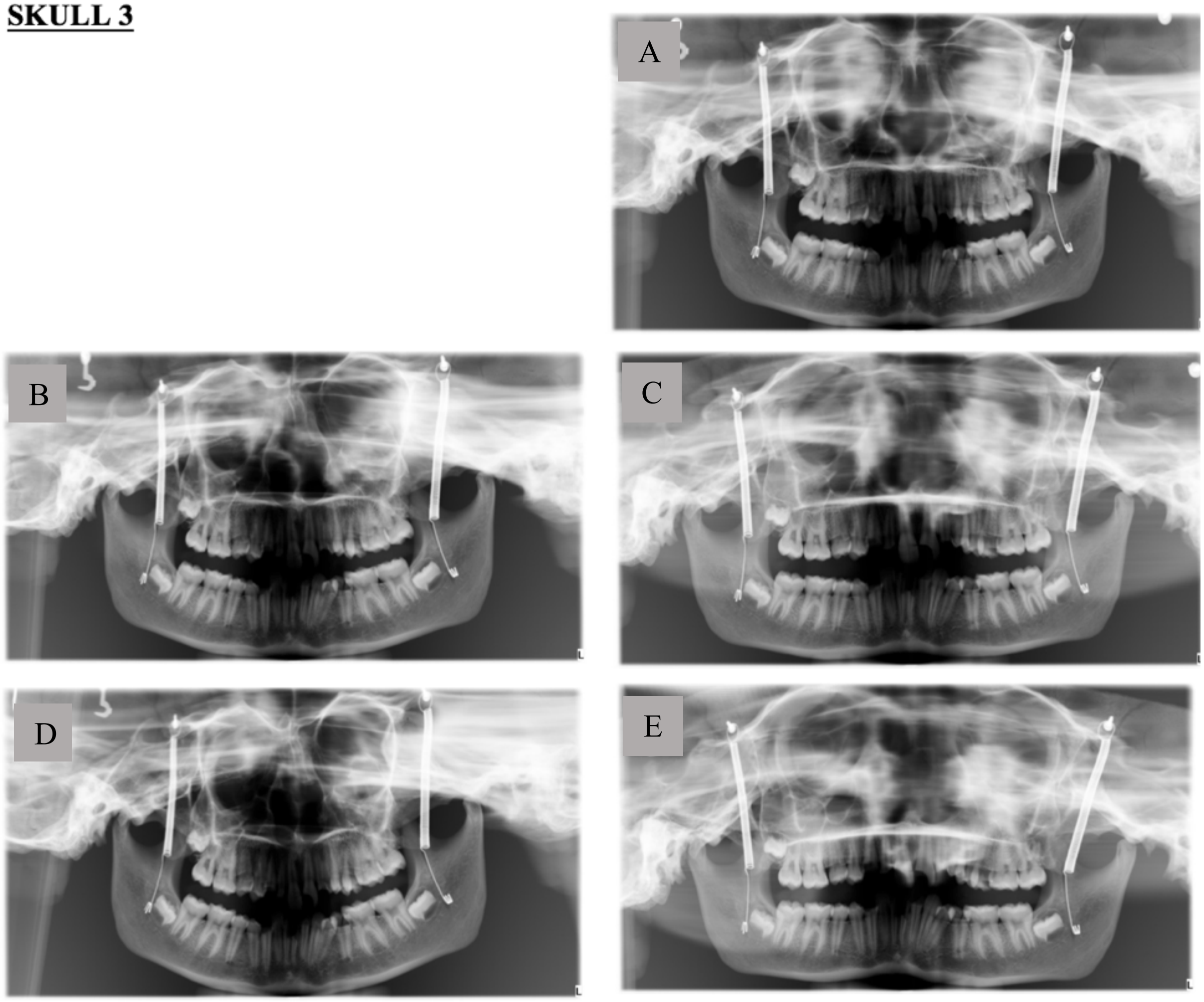

Figure 16. Skull 3.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 4

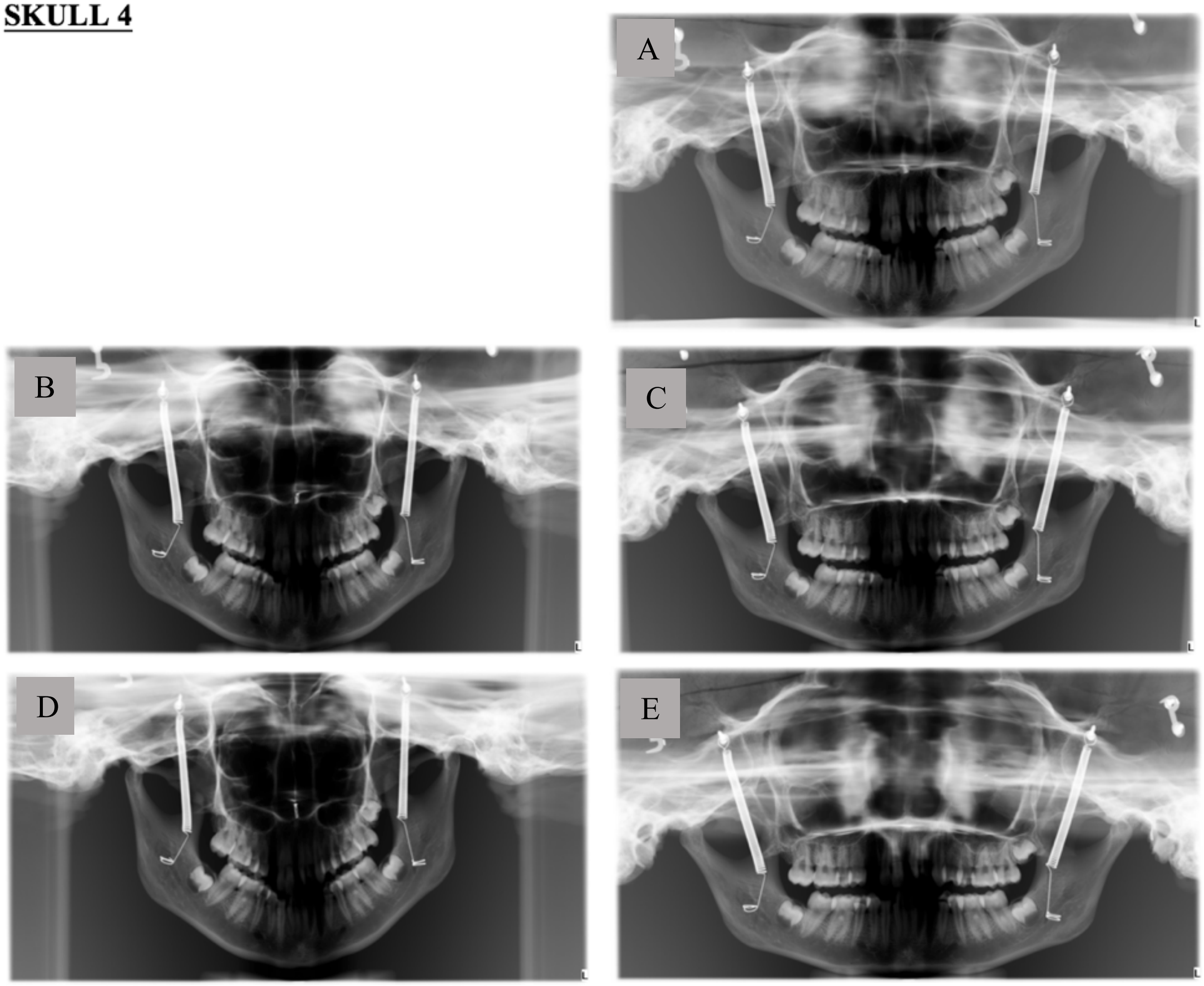

Figure 17. Skull 4.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 5

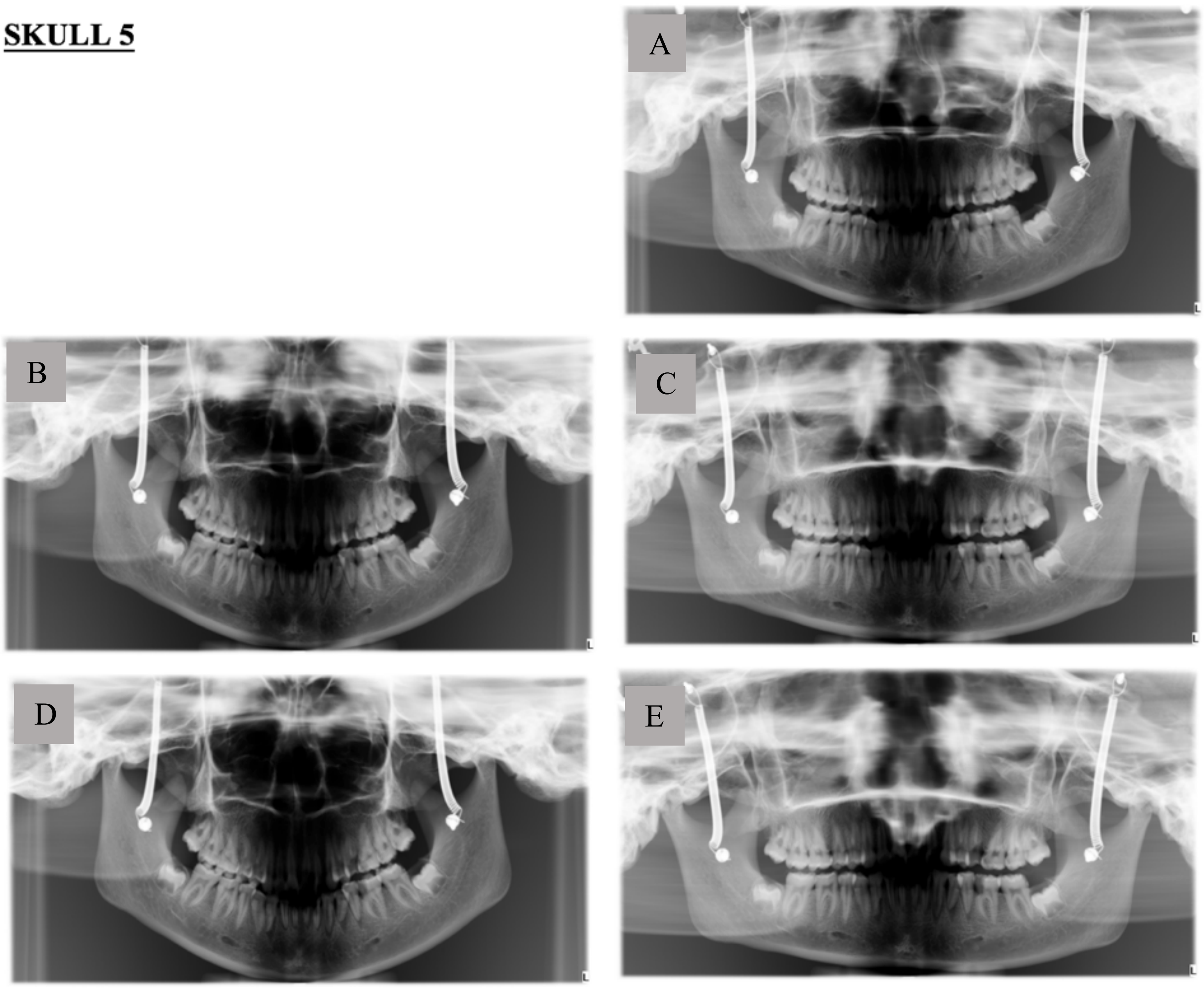

Figure 18. Skull 5.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 6

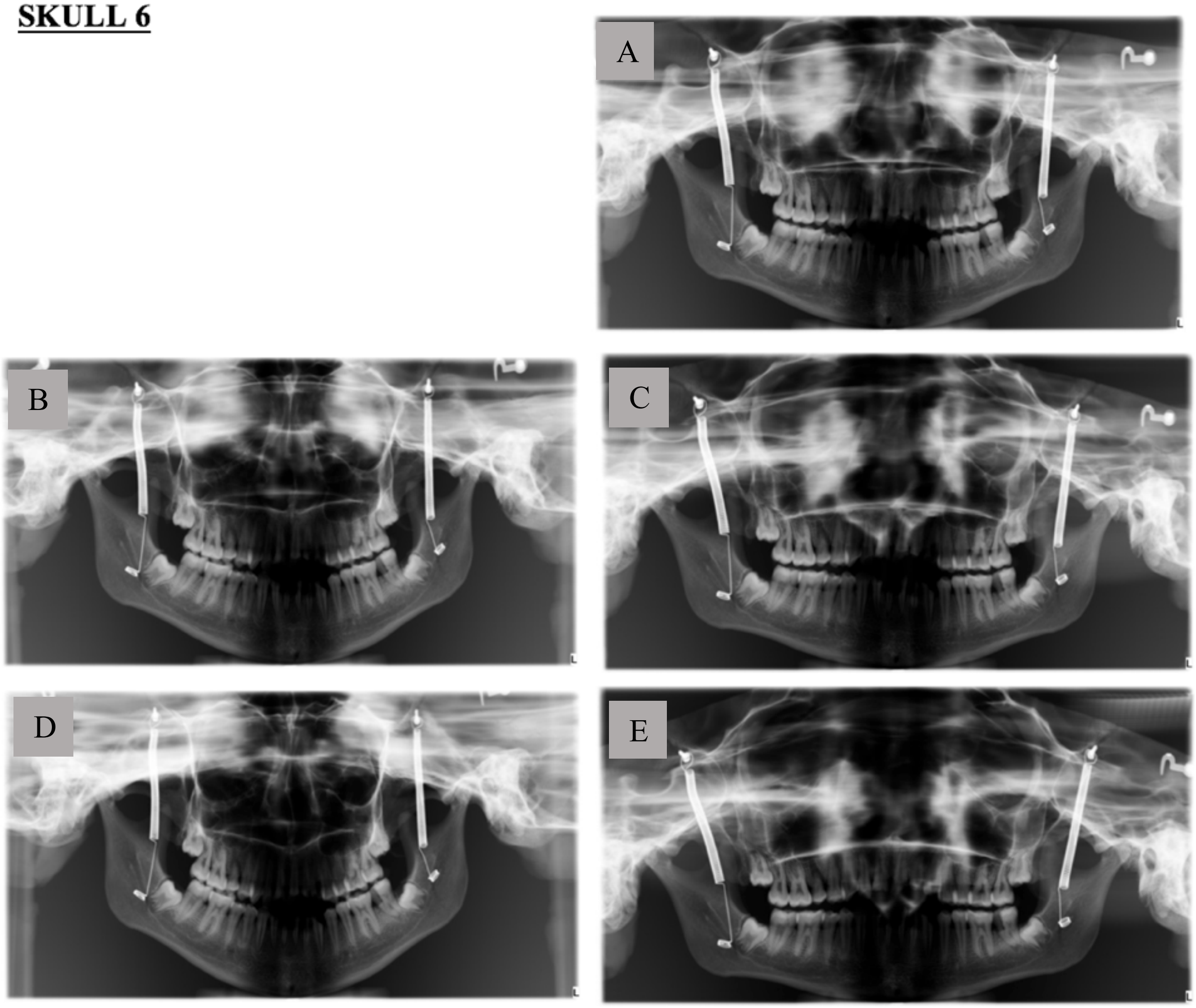

Figure 19. Skull 6.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 7

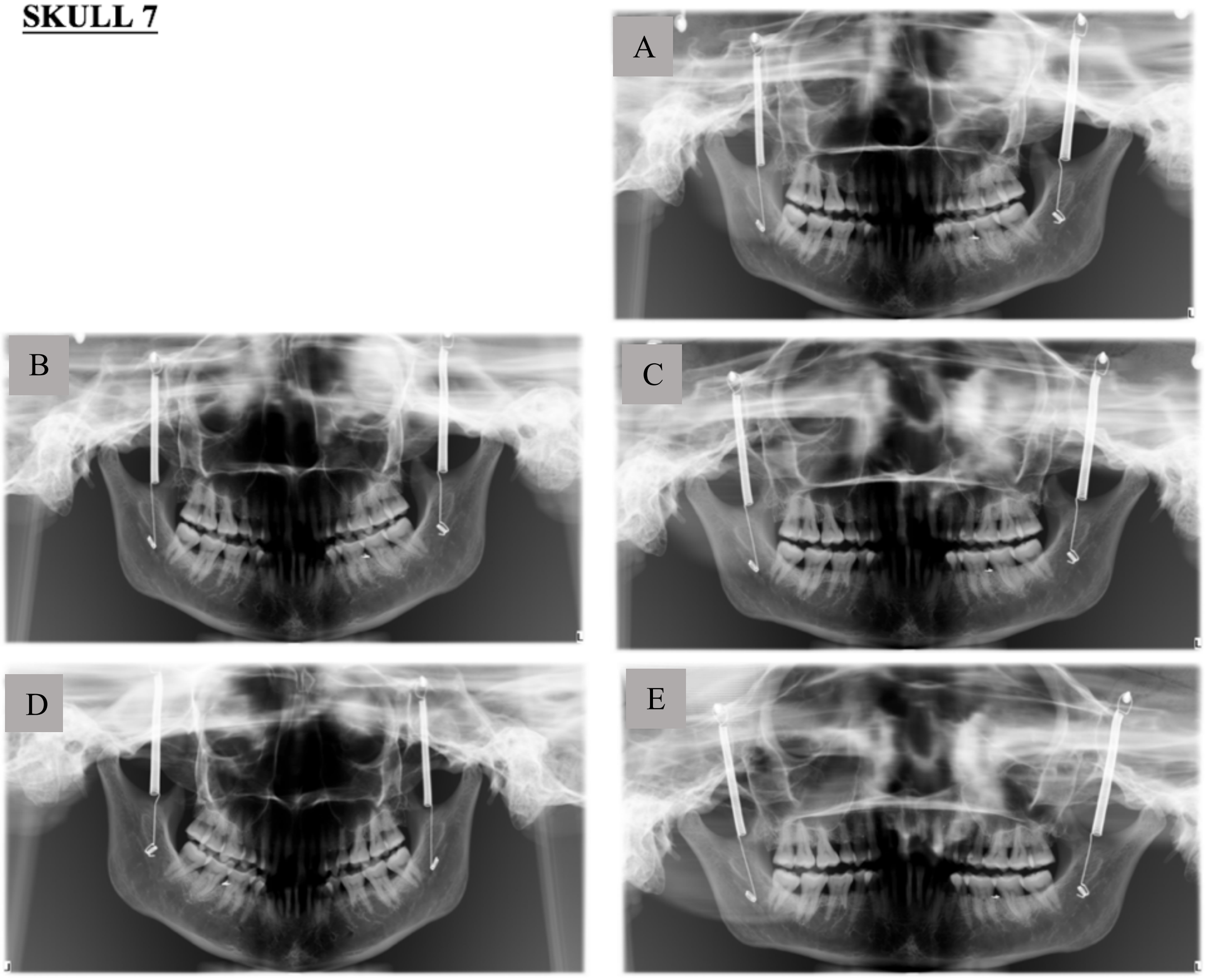

Figure 20. Skull 7.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 8

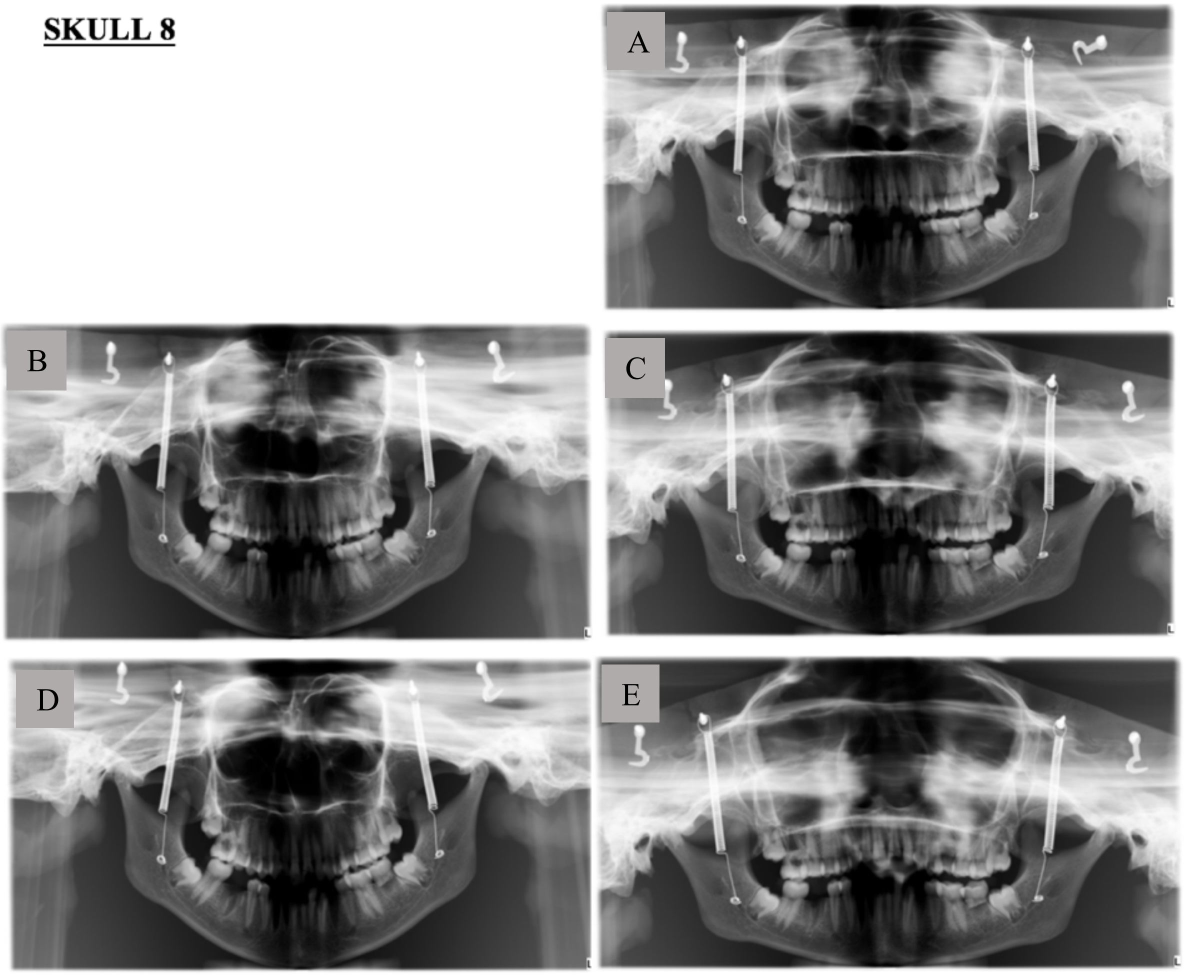

Figure 21. Skull 8.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 9

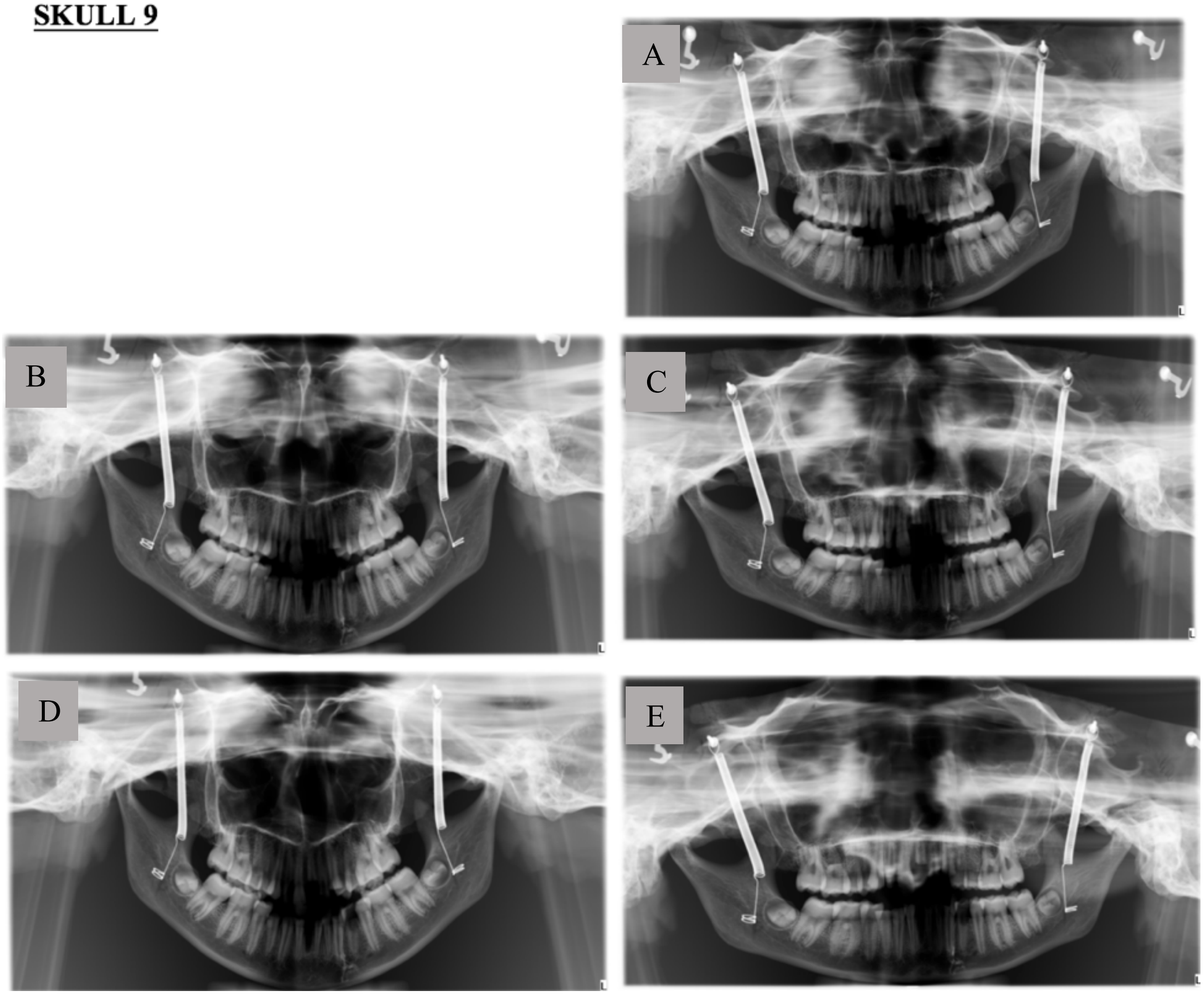

Figure 22. Skull 9.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 10

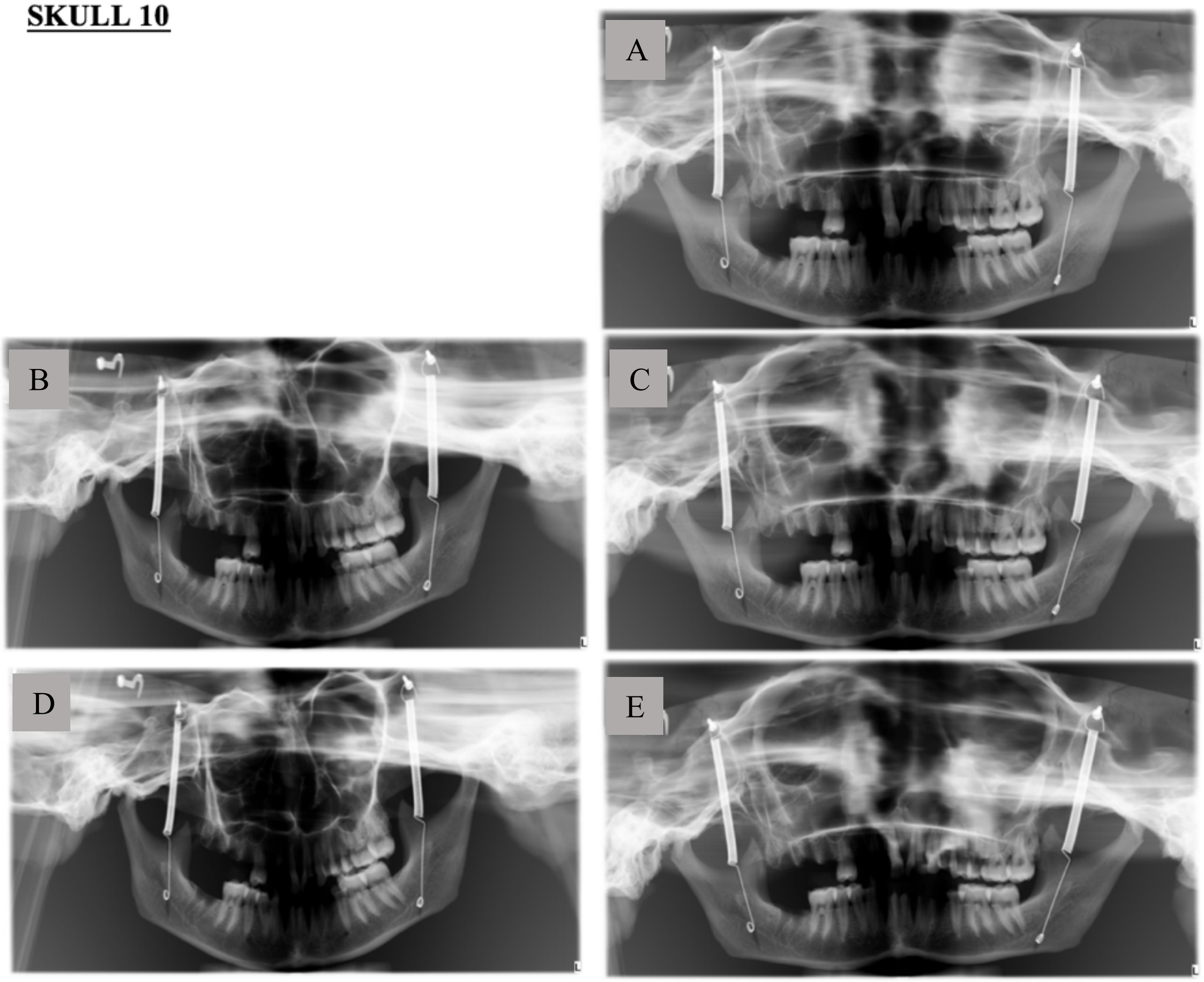

Figure 23. Skull 10.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 11

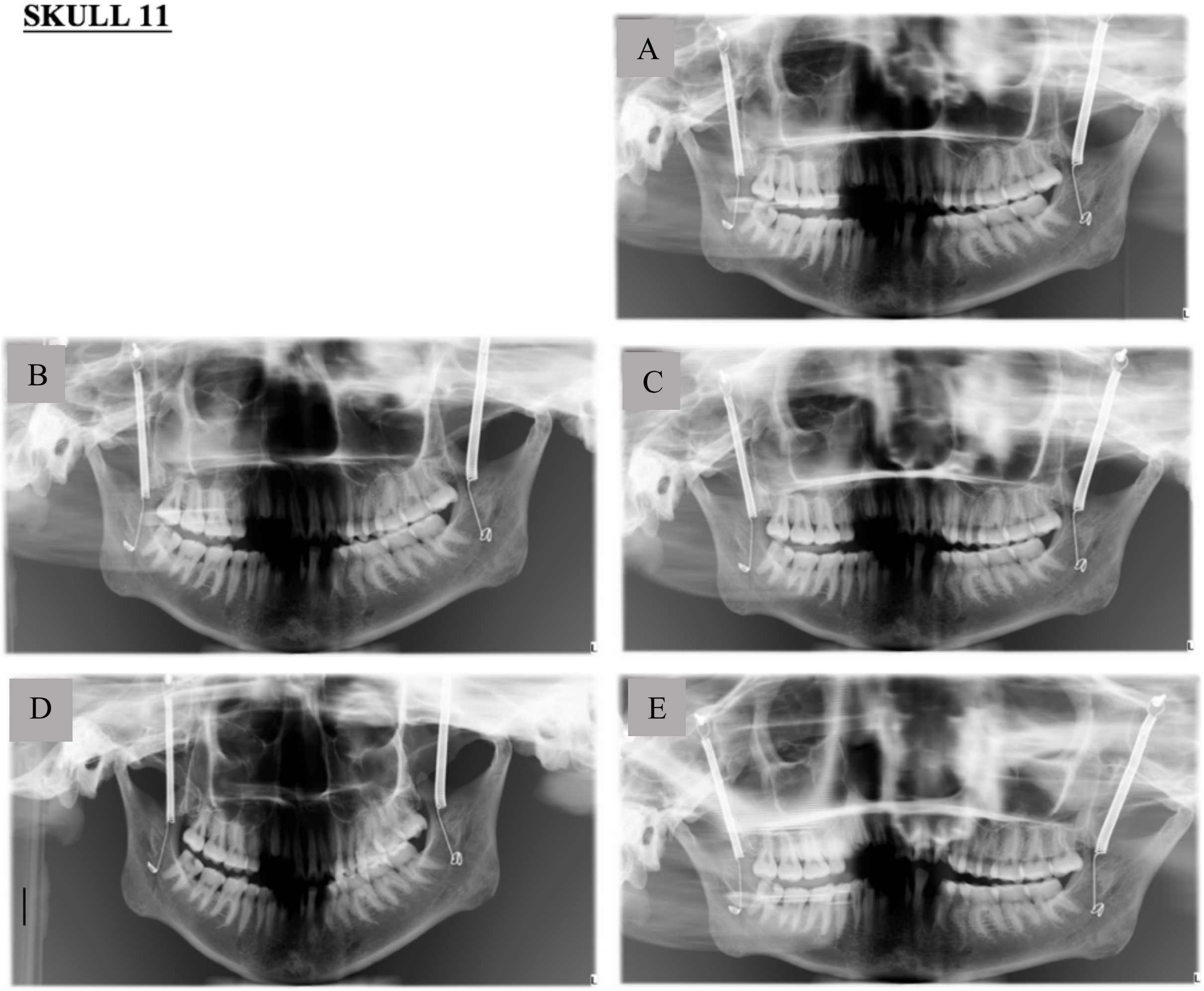

Figure 24. Skull 11.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 12

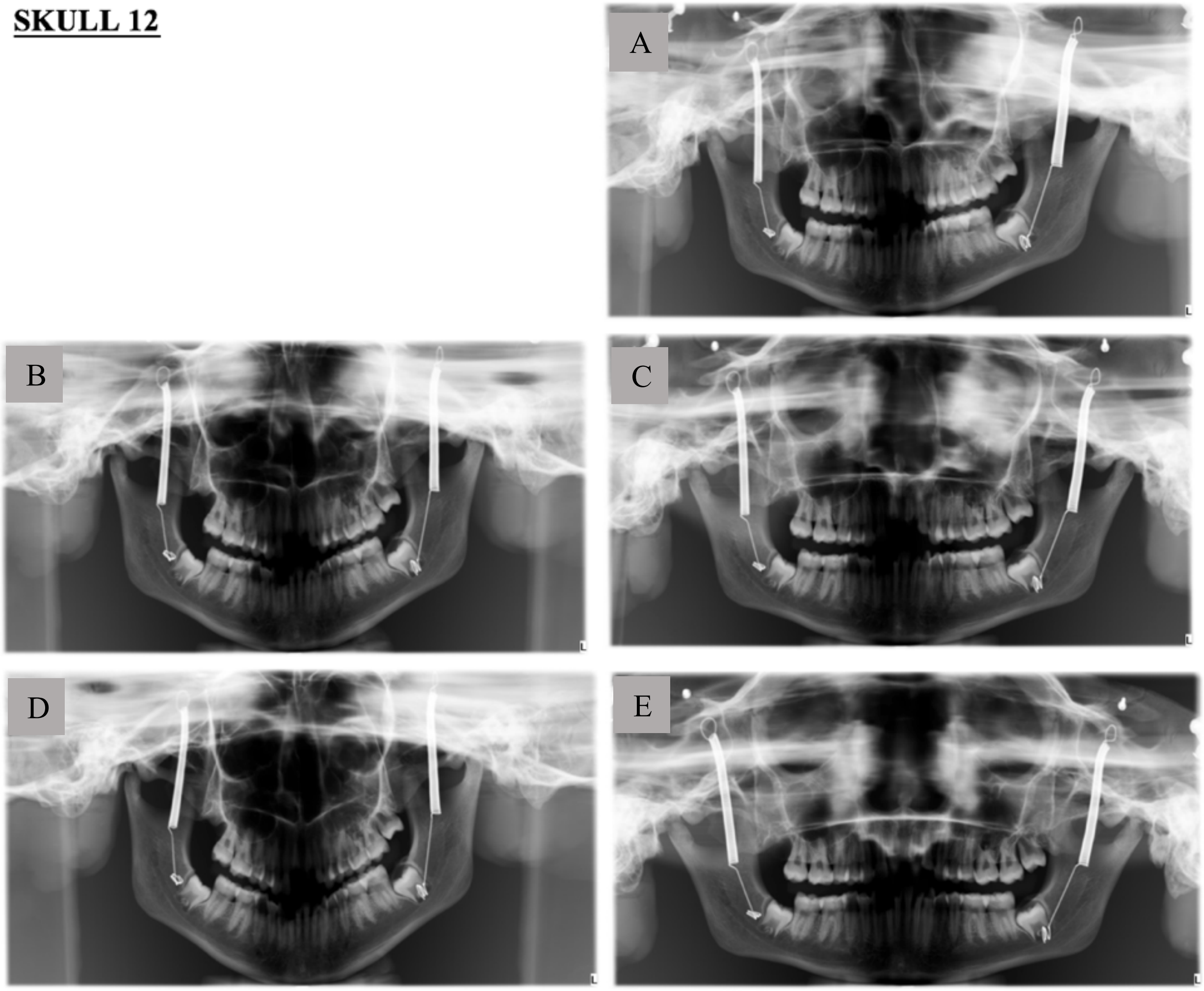

Figure 25. Skull 12.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 13

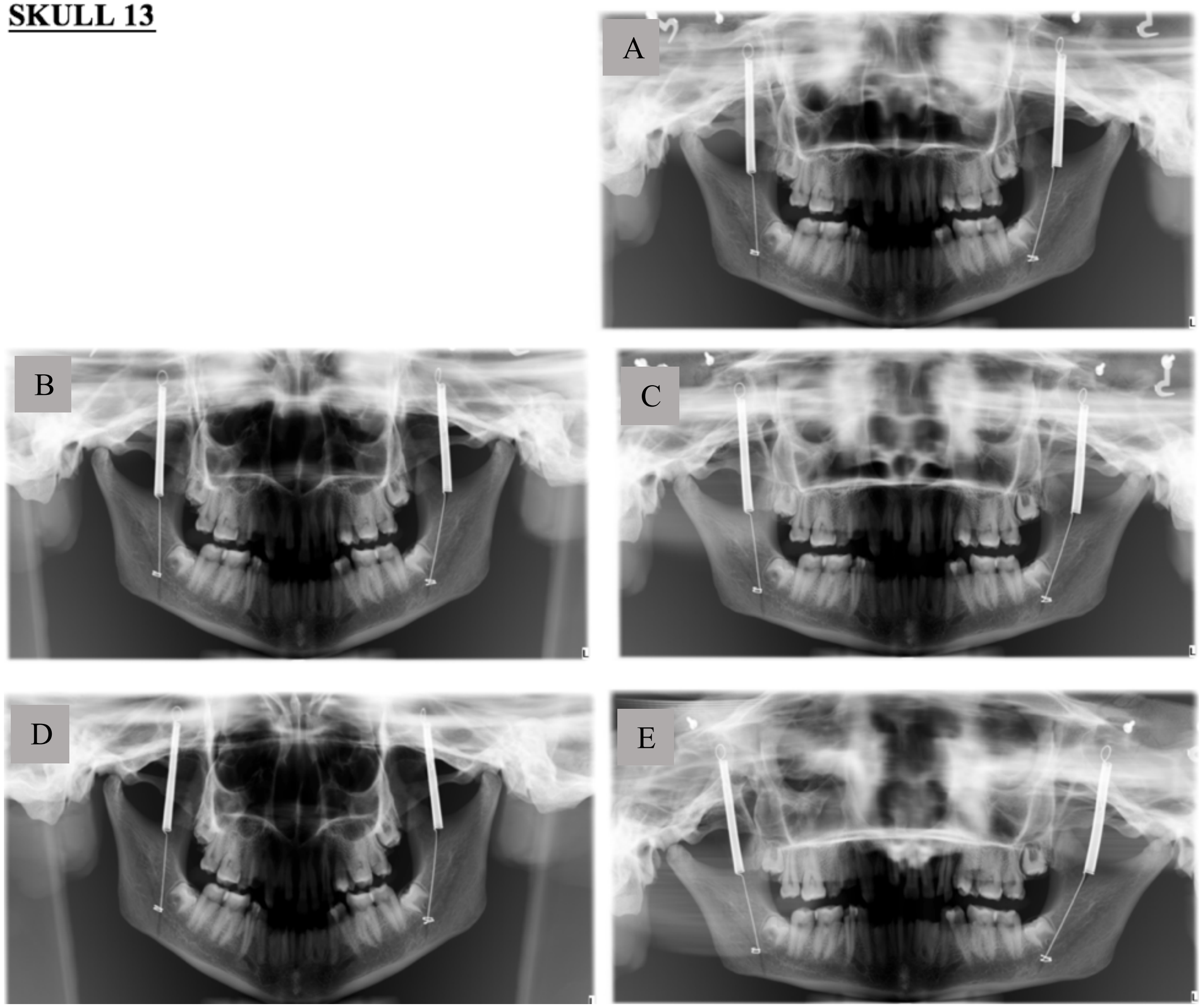

Figure 26. Skull 13.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 14

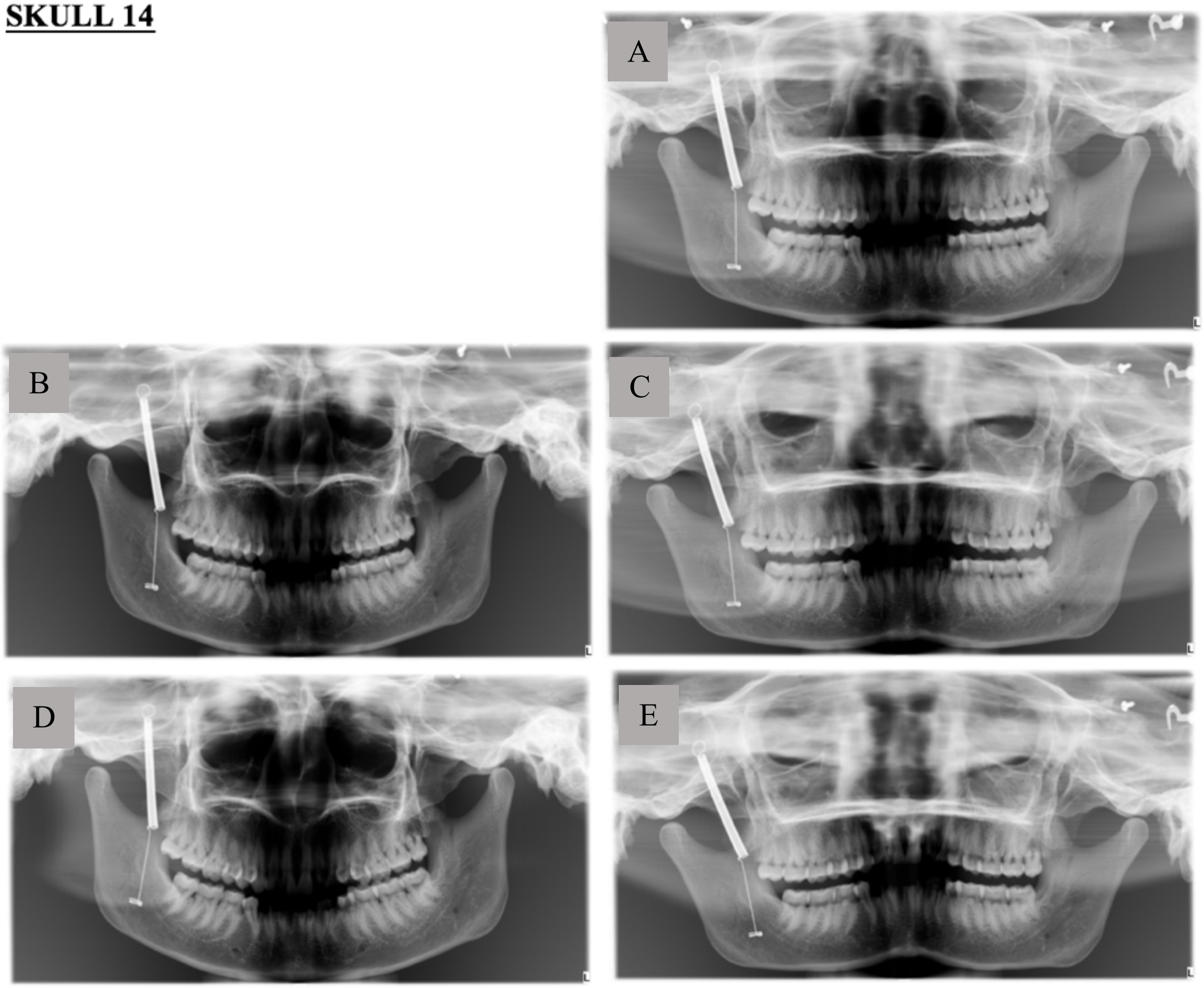

Figure 27. Skull 14.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 15

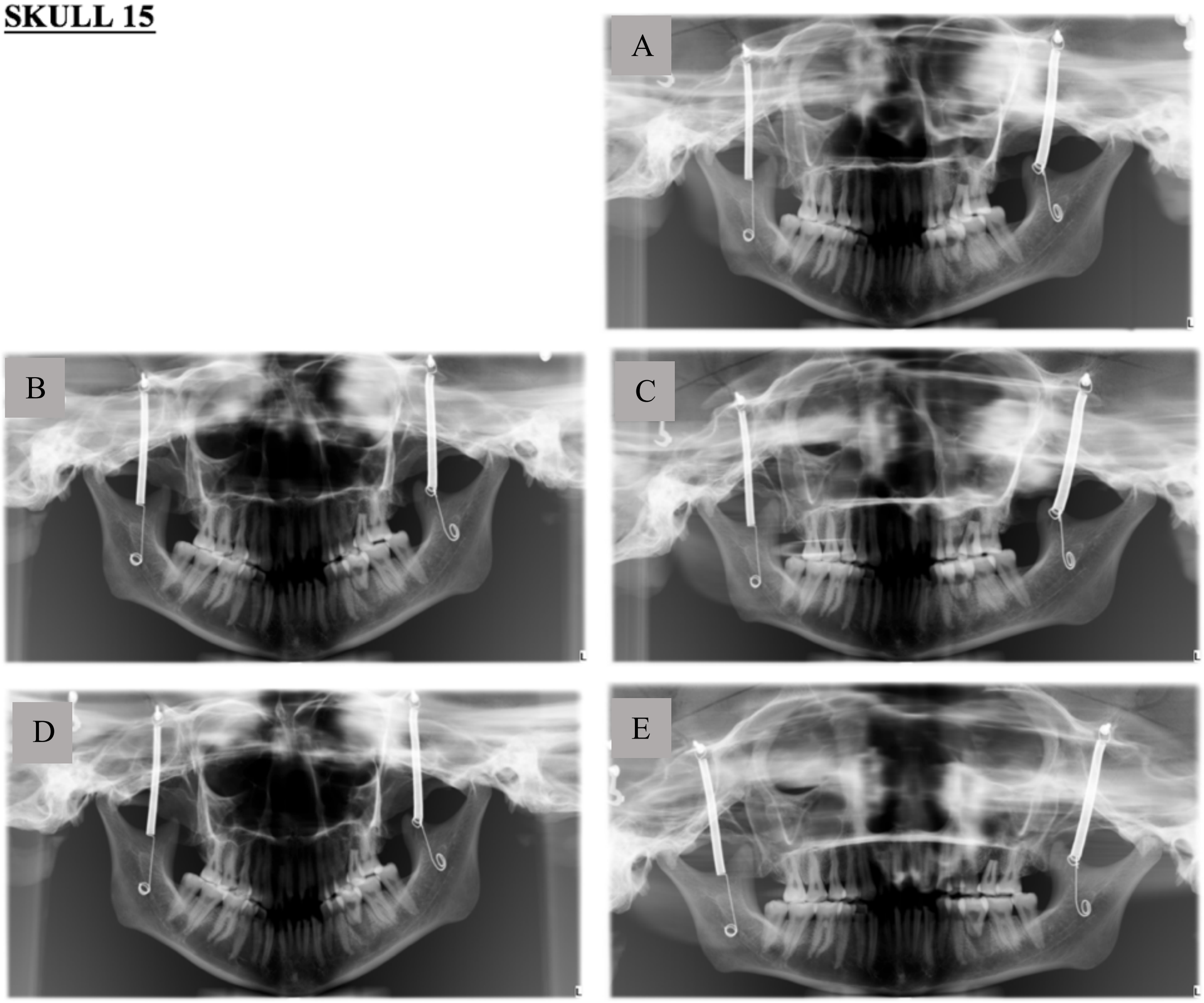

Figure 28. Skull 15.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 16

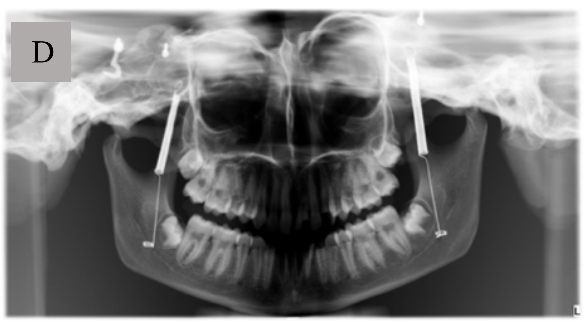

Figure 29. Skull 16.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 17

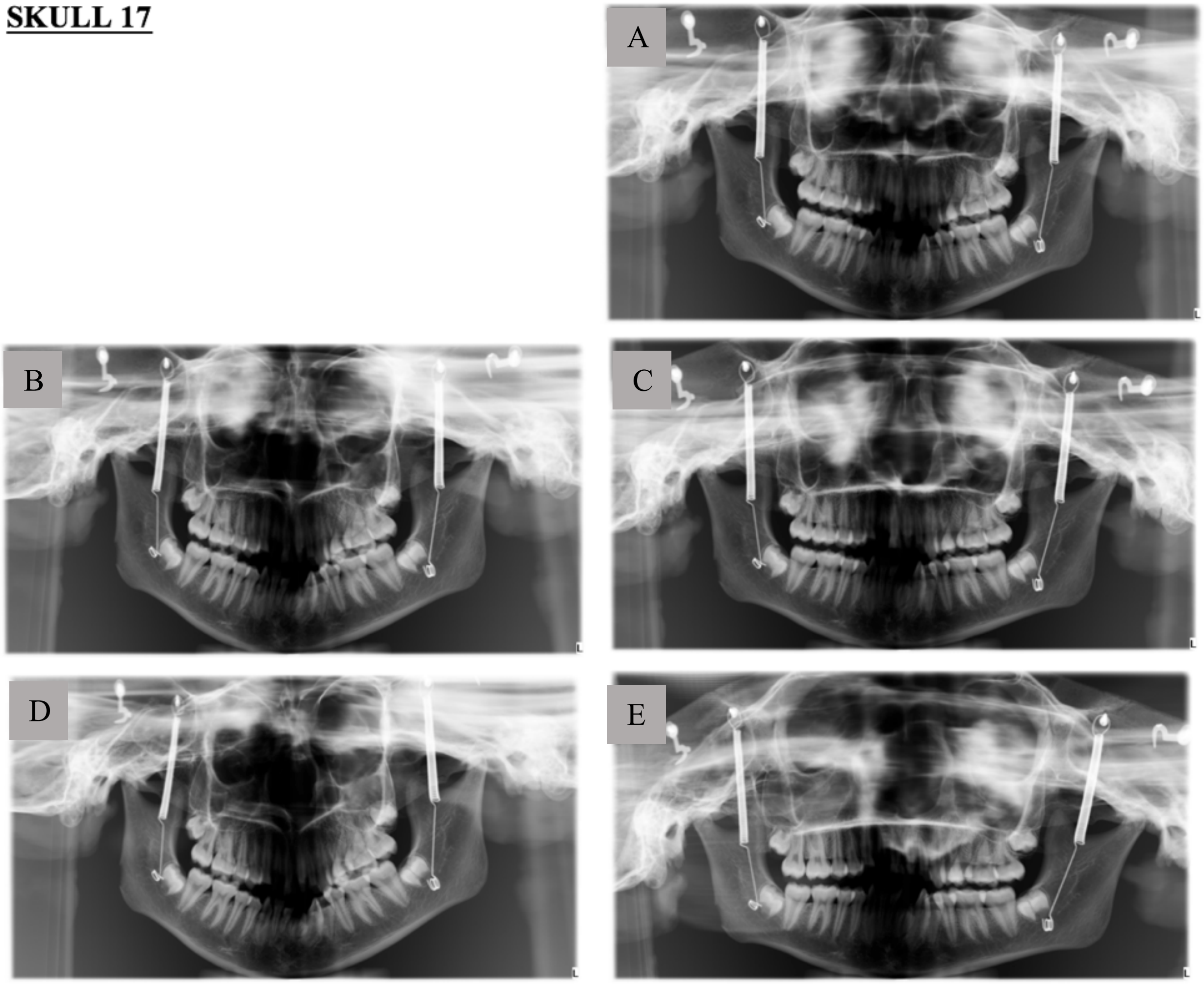

Figure 30. Skull 17.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 18

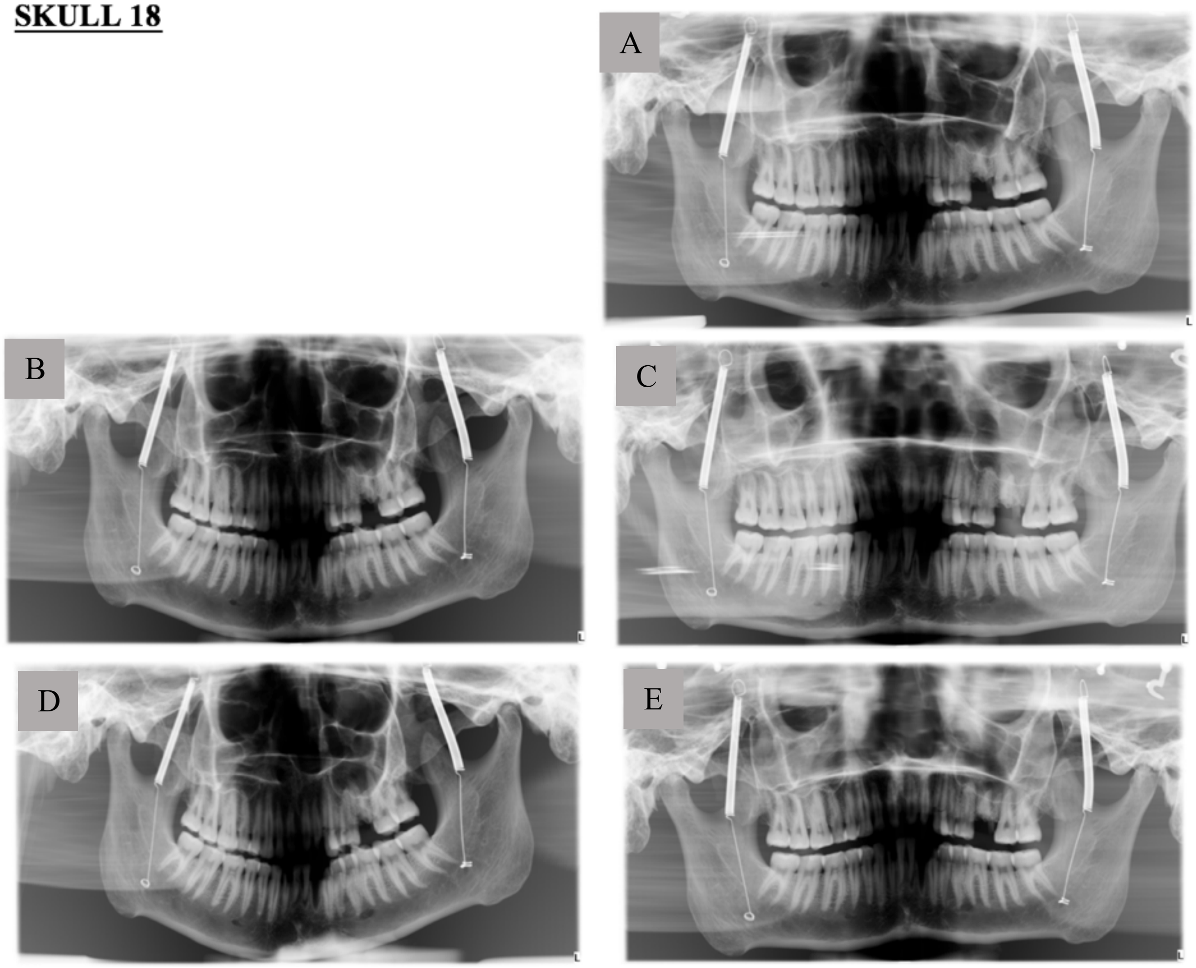

Figure 31. Skull 18.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 19

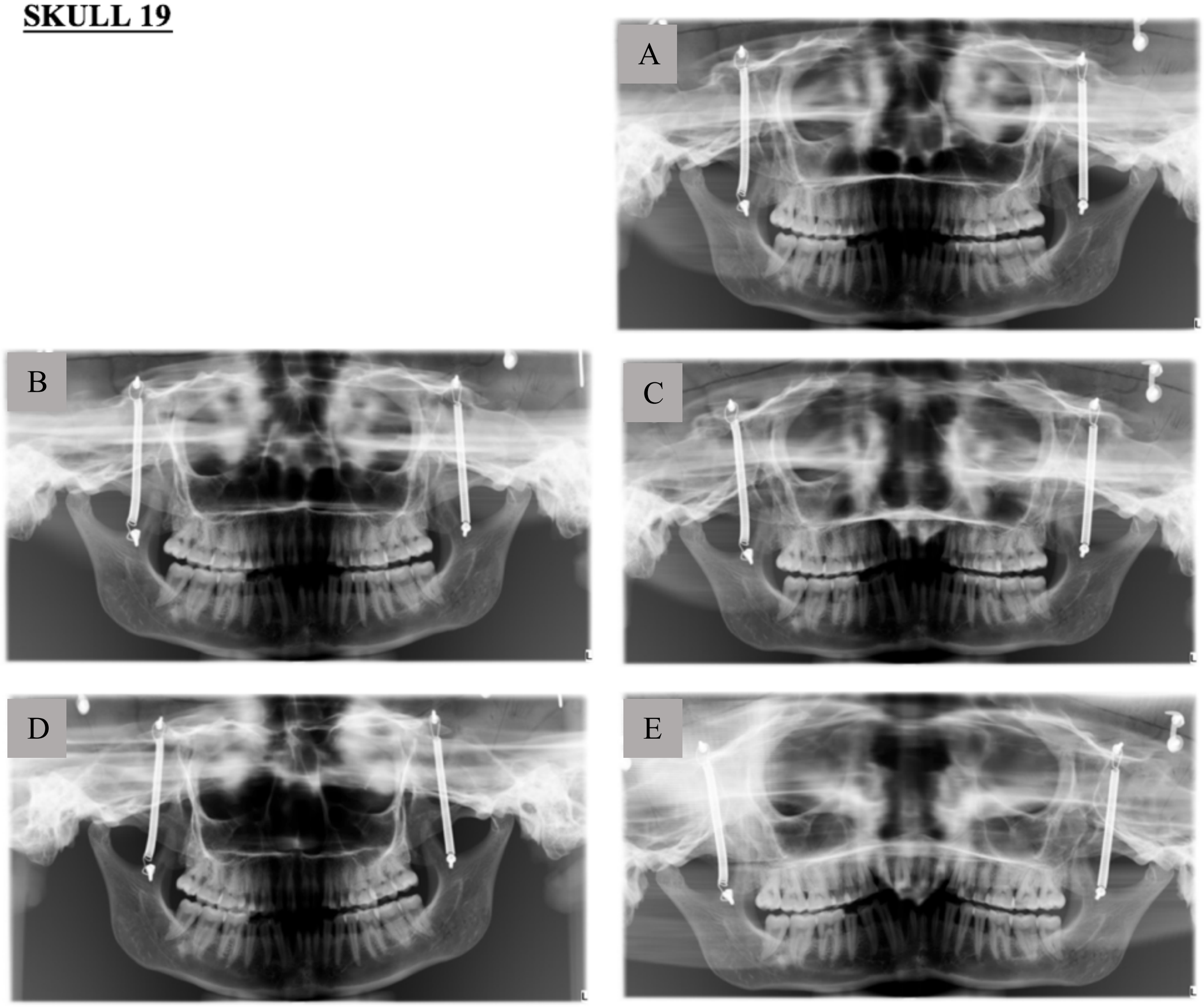

Figure 32. Skull 19.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 20

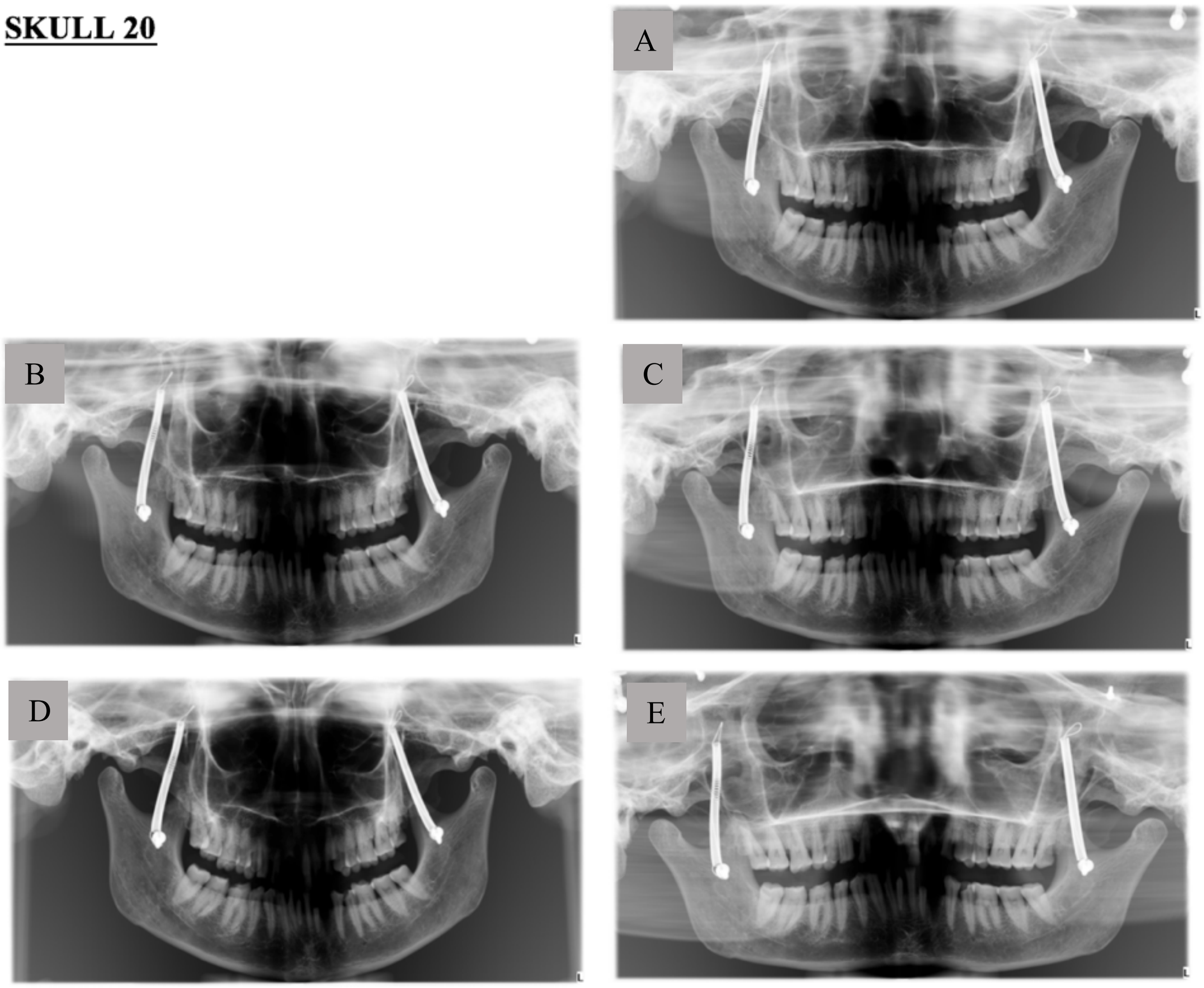

Figure 33. Skull 20.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 21

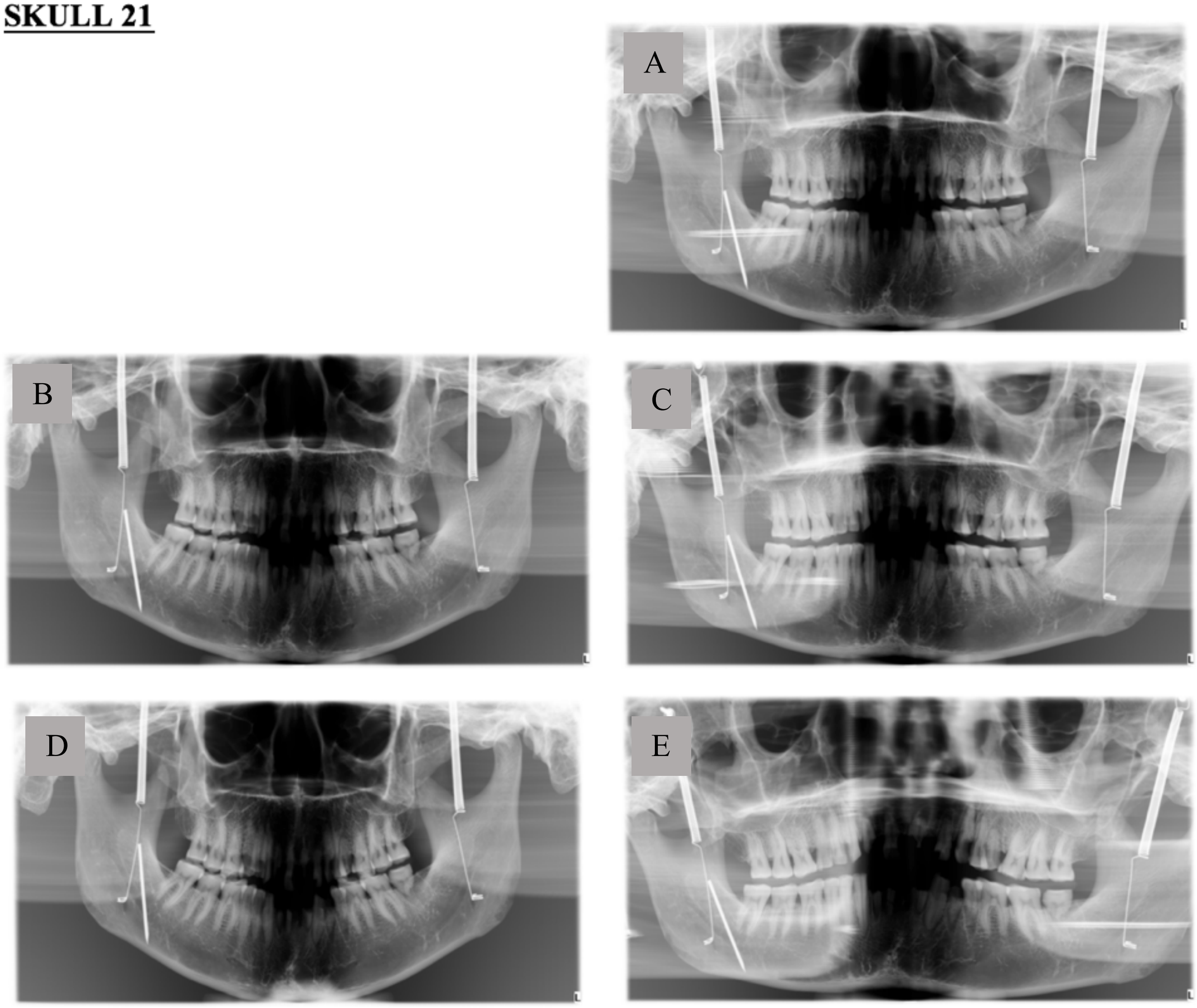

Figure 34. Skull 21.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 22

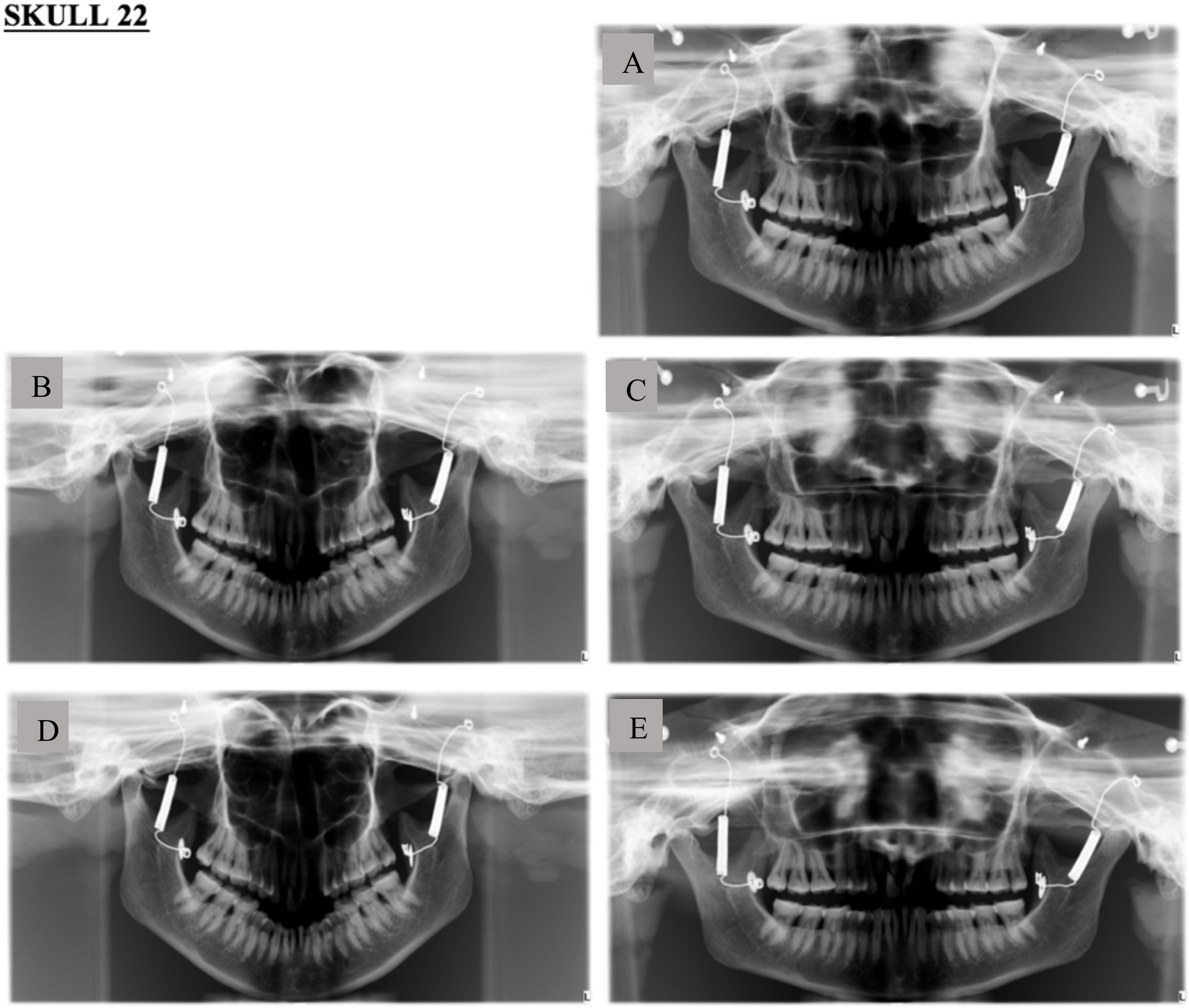

Figure 35. Skull 22.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 23

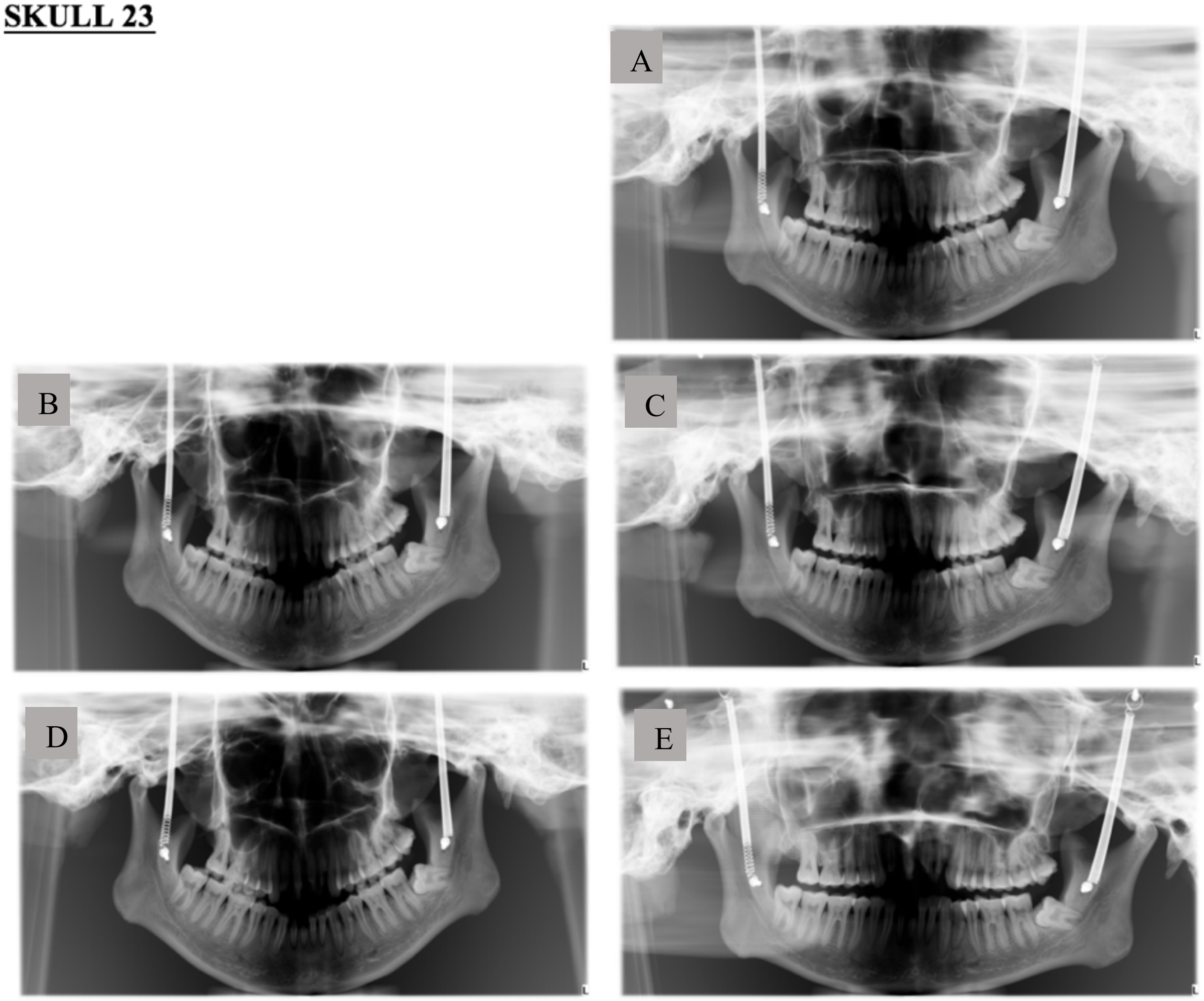

Figure 36. Skull 23.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

APPENDIX B (continued)

PANORAMIC RADIOGRAPHS (continued)

SKULL 24

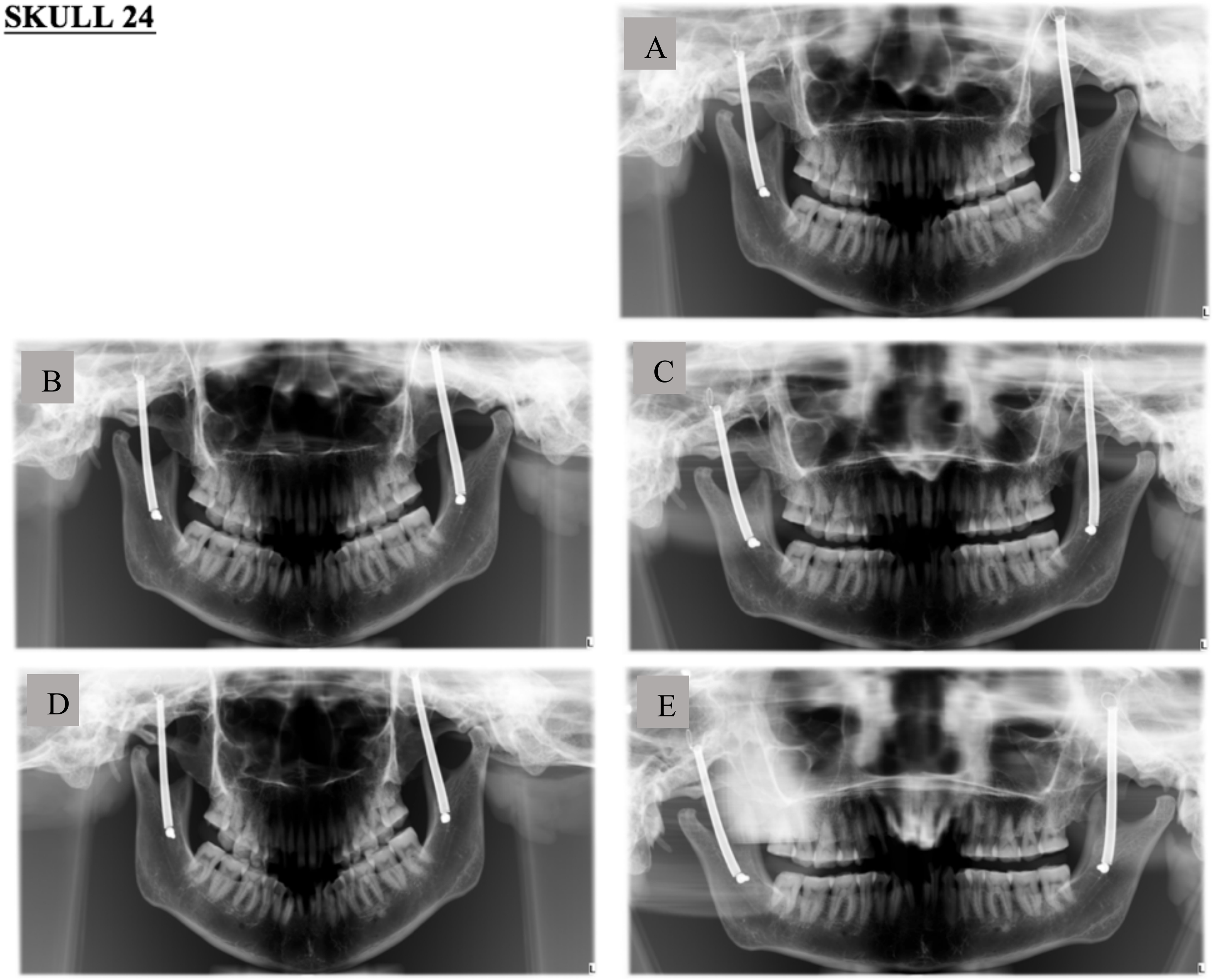

Figure 37. Skull 24.

Panoramic radiographs taken under 0° (A), -5° (B), +5° (C), -10° (D), +10° (E) of head tilt.

VITA

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D.M.D., University of Illinois at Chicago, Chicago, Illinois, 2015

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Specialty Certificate, Orthodontics, University of Illinois at Chicago, Chicago, Illinois, 2018

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Illinois Society of Orthodontists
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A non-traumatic method of a tooth finish margin preparation for porcelain fused to metal restorations. *Collection of scientific works of students of higher educational institutions*. Minsk, Belarus, 2008; 176.

Changes in caries resistance of enamel in primary school children of Minsk using "Elgiflyuor" tooth paste. *European science of the 21st century*. Minsk, Belarus, 2008; 14: 44-46.

Evaluation of dental skills of adolescents using learning efficiency index of oral hygiene. *Materials of the First International Scientific Conference "Innovations in Medicine"*. Kursk, Russia, 2008; 43-44.

Knowledge analysis of mothers of preschool age children about fluoride-containing salt as a source of systemic caries prophylaxis. *Collection of scientific papers, BSMU*. Minsk, Belarus, 2008; 11-14.

Analysis of awareness of pregnant women living in Minsk about methods of systemic fluoride prevention of caries. *The organization of the Public Health*. Minsk, Belarus, 2008; 62-65.

Clinical and laboratory study of the method of a tooth finish margin preparation for PFM crowns with the use of mechanical and chemical gingival sulcus retraction. *Actual problems of modern medicine, BSMU.* Minsk, Belarus, 2007; 65-66.