Third Molar Position and Angulation In Orthodontically Treated Patients With Class II Malocclusion

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THESIS

Submitted as partial fulfillment of the requirements
for the Master of Science in Oral Sciences
in the Graduate College of the University of Illinois at Chicago, 2017

Chicago, Illinois

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DEDICATION

This thesis is dedicated to everyone who has contributed and provided perspective on life.

ACKNOWLEDGEMENTS

I would like to thank my thesis committee Carlotta A. Evans, Marcio da Fonseca, Haitao Li, and Grace Viana for their support and assistance to make this thesis possible. They provided guidance throughout in all aspects of this project and helped me accomplish my goals during the process. I would also like to acknowledge Dr. Ron Jacobson for allowing me to utilize samples from his private practice. Finally, I would like to thank Ahmed Masoud and. Linping Zhao for their ideas and guidance to implementing the methodology.

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LIST OF ABBREVIATIONS

CBCT	Cone-Beam Computer Tomography
MARA	Mandibular Anterior Repositioning Appliance
3D	Three Dimensions

SUMMARY

Mandibular third molar impaction is a major problem for dental practitioners and patients. During development, third molars undergo important pre-eruptive rotational and angular movements (Silling, 1973; Huggins, 1962; Richardson, 1978). Orthodontic treatment in young adolescents can affect rotational and angular movements in impacted third molars. The main issues in orthodontics regarding third molars presently discussed are its fate, specifically whether or not the tooth will erupt or become impacted.

The purpose of the present study was to determine in 3D whether Class II correction with non-extraction appliance therapy with mandibular advancement results in favorable rotational and positional changes in the mandibular third molar. This study will evaluate the changes in 3D in mandibular third molar position and angulation from pre-treatment to post-treatment in Class II patients treated to Class I and will be compared to patients who were initially Class I treated orthodontically.

The CBCT pre-treatment and post-treatment analysis was performed with Invivo 5. This program allowed for the development of a custom analysis to determine the measurements carried out in the study. First, stable landmarks were identified to produce a stable reference plane. Next, landmarks on the third molar identified a series of points, lines, and angles for measurement determination. Finally, positional and angular changes in pre-treatment and post-treatment CBCTs were compared using paired t-tests within each group and independent-sample 2-tailed t-test between groups.

1. INTRODUCTION

1.1 Background

Mandibular third molar impaction is one of the major problems faced in the dental profession (Peterson, 1992). Characterized by large variability in development, the third molars present as the teeth with the highest rate of impactions (Dachi et al., 1961; Bishara et al., 1982). In the majority of cases in orthodontic treatment, third molars are not directly involved in the treatment; however, they can influence the latter or be influenced by it, which dictates their importance in the treatment planning process. Most mandibular third molar studies have concentrated on the influence that the third molars have on the rest of the dentition, rather than on the control that the rest of the dentition has on the third molars (Staggers et al., 1992; Van der Schoot et al., 1997; Sidlauskas and Trakiniene, 2006). The causes for third molar impaction and prediction of third molar eruption have also been studied extensively. In contrast, the effect of orthodontic treatment on the developing third molars has not been subjected to much investigation.

Predicting the fate of third molars is difficult, since the second molars of an average 12-year old orthodontic patient have not yet erupted and they have had limited calcification at that time. Since this is usually the optimum age for treatment of most malocclusions, it becomes important to know whether and how the third molars are developing while formulating an orthodontic treatment plan (Richardson, 1980).

Developing third molars undergo important pre-eruptive rotational movements (Silling, 1973; Huggins, 1962) and they continually change their angular positions (Richardson, 1978). These rotational movements take place when the third molar bud comes into close proximity to the second molar, and if these rotational movements fail to occur, impactions are inevitable (Silling, 1973). Therefore it will be useful to discover the effects appliance therapy has on the crucial positional and angular movements on the developing third molars. In a study by Richardson (1997), class II cases with mandibles shorter in length, narrower in width, and more acutely angled were more prone to mandibular third molar impaction. A reduced amount of mandibular growth in cases with impacted third molars was also noted. The developmental initial mesial angulations of third molars in relation to the mandibular plane was also increased in subjects with impacted third molars (Richardson, 1997).

It has been suggested that appliance therapy that holds back the mandibular molars or actively tips them distally may have the effect of encouraging abnormal rotational and positional movements of the third molar crown increasing risk of impaction. In contrast, favorable movement caused by appliance therapy on the buccal segments may have the effect of favorable mesial movement and uprighting rotational changes in the developing mandibular third molars, thereby decreasing the possibility of impaction (Silling, 1973).

The purpose of the present study was to determine in 3D whether Class II correction with non-extraction appliance therapy with mandibular advancement results in favorable rotational and positional changes in the mandibular third molar. This study evaluated the changes in 3D in mandibular third molar position and angulation from pre-treatment to post-treatment in Class II patients treated to Class I and compared them to patients who were initially Class I treated orthodontically with appliance therapy.

1.2 Objectives

To evaluate in 3D the treatment effects on the mandibular third molar angulation and position of Class II Division 1 patients pre-treatment to post-treatment with non-extraction orthodontic therapy with mandibular advancement.

To evaluate in 3D the treatment effects on the mandibular third molar angulation and position of Class I malocclusion patients pre-treatment to post-treatment with non-extraction orthodontic therapy.

To determine differences between non-extraction orthodontic appliance therapy and third molar angulation and position in Class II Division 1 malocclusion compared to Class I malocclusion patients pre-treatment to post-treatment.

To determine differences between mandibular third molar position and angulation in the same patient on the right and left pre-treatment to post-treatment in Class II Division 1 malocclusion patients.

To determine differences between mandibular third molar position and angulation in the same patient on the right and left pre-treatment to post-treatment in Class I malocclusion patients.

1.3 Null Hypothesis

H(1): No changes occur in mandibular third molar position and angulation in orthodontically treated patients with Class II Division 1 malocclusions pre-treatment to post-treatment.

H(2): No changes occur in mandibular third molar position and angulation in orthodontically treated patients with Class 1 malocclusions pre-treatment to post-treatment.

H(3): No differences are found in mandibular third molar position and angulation in orthodontically treated patients with Class II Division 1 malocclusions pre-treatment to post-treatment between the patient's right and left mandibular third molars.

H(4): No differences are found in mandibular third molar position and angulation in orthodontically treated patients with Class I malocclusions pre-treatment to post-treatment between the same patient's right and left mandibular third molars.

H(5): No differences are found in mandibular third molar position and angulation in orthodontically treated patients with Class II Division 1 malocclusion and Class I malocclusion pre-treatment to post treatment.

2. LITERATURE REVIEW

2.1 Development of Mandibular Third Molars

The development of the mandibular third molar and its influence is of considerable concern to orthodontists due to its unusual nature characterized by variability in developmental path, formation, calcification timing, crown and root morphology, position, and course of eruption. The mandibular third molar begins calcification at approximately 8-10 years of age and eruption, if it occurs, will be initiated between the ages 17-21 years old (Logan et al., 1933). It is the last permanent tooth in the human dentition to erupt and frequently becomes impacted.

2.2 Anatomy of Mandibular Third Molars

The third molars of the mandibular dentition are found on the right and left sides situated at the distal end of the body of the mandible, and are the eighth tooth from the midline (Kay and Killey, 1976). There is considerable variation in the appearance of its form, shape and size. As a molar, it functions similarly to the other two mandibular molars and therefore its overall appearance is similar. It may generally be smaller in appearance accompanied with smaller surfaces, a larger number of supplemental grooves, and four to five cusps which cannot be as sharply elucidated as those of the first and second mandibular molars.

2.3 Third Molar Positioning and Role in Orthodontics

The orthodontist needs to incorporate management of the third molars into treatment planning and should be cognizant of the relationship of the third molars to the rest of the dentition. A majority of patients receive orthodontic treatment during active growth period and the effect of the dentition on third molars becomes crucial. The main issues in orthodontics presently discussed are the fate of the mandibular third molar, specifically whether or not the tooth will erupt or become impacted, whether orthodontic treatment involving permanent teeth extraction will have an effect on crowding and influence eruption of mandibular third molars, and whether mandibular third molars influence the rest of the dentition and will cause crowding of the mandibular incisors.

2.3.1 Impaction of Mandibular Third Molars

Impacted mandibular third molars are one of the most common findings among patients seen by dentists. A dental impaction was defined by Mead (1954) as a tooth that is prevented from erupting into position due to malposition, lack of space, or other impediments. Peterson (1992) later defined impacted teeth as those teeth that fail to erupt into the dental arch within the expected time. In 2004, Farman defined impacted teeth as those that are prevented from eruption due to a physical barrier within the path of eruption. The eruption timing for mandibular third molars has been generally found to erupt between the ages of 17 and 21 years (Logan and Kronfield, 1933). The possibility of eruption of mandibular third molars or the potential impaction is important to consider in orthodontic treatment and long-term management of the dentition post-orthodontic treatment. The potential causes influencing eruption or impaction began with studies on growth. Limited retromolar space in 90% of third molar impaction cases was reported in an early study by Björk et al. (1956). In a later study he concluded that four factors, two skeletal and two dental, were identified to be associated with the impaction of mandibular third molars: a vertical direction of condylar growth, reduce mandibular length, a backward-directed eruption of the mandibular dentition and a retard maturation of the third molar (Björk, 1963). A longitudinal study involving subjects with skeletal Class II, with mandibles shorter in length, narrow in width and more acutely angled were more prone to impaction of mandibular third molars (Richardson, 1997). In an attempt to devise a method to predict third molar impaction; Schulhof (1976) determined that if the distance from the Xi cephalometric point to the distal surface of the second permanent molar was less than 25mm, impaction became more likely and less likely as the length increased towards 30mm. However, this method of prediction presupposes impaction is related solely to available space and does not take into account other confounding factors such as pre-eruptive movements and initial position and angulation of the third molar. These investigators have determined that there is a correlation between growth and skeletal characteristics with third molar impaction. The common associated factor seems to be lack of available eruption space due to variations in growth patterns.

The third molar developmental position and angulation are other considerations influencing eruption of mandibular third molars. Richardson (1997) found that the initial mesial angulation in relation to the mandibular plane was increased in subjects with mandibular third molar impactions. To further validate that there are factors beyond growth contributing to impaction, a study was conducted by Ades et al. (1990) which concluded there was no significant differences in mandibular growth between those with impactions and those with fully erupted mandibular third molars. Other studies have described the positional changes and eruption of impacted mandibular third molars as unpredictable (Hattab, 1997; Erdem et al., 1998). The study by Hattab came to this conclusion due to discovering a significant proportion of mesially impacted mandibular third molars had a change in angulation and became fully erupted by 24 years of age (Hattab, 1997), whereas Erdem et al. (1998) described a greater mesial inclination of the impacted lower molars contributing to their occurrence of impaction (Erdem et al., 1998). As impaction of the mandibular third molars is correlated with certain skeletal characteristics, most commonly the availability of eruption space, an increased third molar angulation seems to be significantly linked to third molar impactions as well.

2.3.2 Orthodontic Treatment

Most mandibular third molar studies have concentrated on the influence that the third molars have on the rest of the dentition rather than on the control that the rest of the dentition has on the third molars. The causes for third molar impaction and prediction of third molar eruption have also been studied extensively. Most investigations have been conducted on the influence of mandibular third molars on the rest of the dentition. In contrast, the effect of orthodontic treatment on the developing third molars has not been subjected to much investigation.

Orthodontic treatment may significantly influence the development of the dentition especially since majority of treatment takes place during active growth. Orthodontic appliance therapy has an effect on mandibular third molars in various ways. A broadly investigated effect of treatment has been in orthodontic extraction therapy, in which the majority of investigators have reported a positive influence of the removal of teeth for orthodontic purposes on the resulting position and angulation of mandibular third molars (Elsey and Rock, 2000; Rindler, 1977; Cavanaugh, 1985; Gooris et al., 1990; Richardson and Richardson, 1993; Kim et al., 2003; Jain and Valiathan, 2009; Mihai et al., 2013). This influence can be beneficial in treatment decisions involving borderline extraction therapy cases that can impact mandibular third molars such that it could produce favorable position for their eruption or even minimize possible complications during surgical removal in the future.

In contrast to the conclusions drawn from the studies on orthodontic extraction therapy, a study by Staggers et al. (1992) concluded that there was no impact of extractions on third molar angulation. The vast majority of studies surrounding effects of orthodontic treatment on third molars has been focused on that of orthodontic extraction therapy on mandibular third molars has been broadly investigated. It is equally as important to investigate the effect of orthodontic treatment on non-extraction cases due to the growing trend of non-extraction orthodontic therapy and the insufficient studies to support the effects of orthodontic appliance therapy on the mandibular third molars.

2.3.3 Mandibular Incisor Crowding

The effect of mandibular third molar position and eruption stage on the rest of the dentition has been presented with opposing views. This is of great concern to orthodontists because there is no research evidence in support of the prophylactic extraction of non-pathological impacted third molars. The systematic review by Costa et al. (2013) has concluded there is a need for higher quality research in order to come to more definitive treatment recommendations on the clinical management of third molars. During investigations that were conducted prior to the 1990's, the conclusions drawn suggested that mandibular third molars were more significantly associated with the crowding in the lower arch (Dewey, 1917; Bergstrom et al., 1961; Sheneman, 1968; Lindquist and Thilander, 1982). In contrast, the more recent studies perceive prophylactic third molar removal as unjustifiable (Van der Schoot et al., 1997; Sidlauskas and Trakiniene, 2006; Hasegawa et al., 2013; Karasawa et al., 2013). However, clinical recommendations suggest in cases where extraction of mandibular third molars is indicated, it is preferable to have them extracted prior to adulthood due to the increase in risk of complications with age (Phillips et al., 2010).

2.4 <u>Class II Division 1 Malocclusion</u>

2.4.1 Features of Class II Division 1 Malocclusion

Class II malocclusions are prevalent in 11% of the US population and accounts for 20% to 30% of all orthodontic patients (Profitt et al., 1998). The etiology of Class II Division 1 malocclusions can be due to skeletal discrepancy, soft tissue origin, and habits. The skeletal presentation of Class II Division 1 patients can include a genetic component that expresses as a prognathic maxilla, a retrognathic mandible, or a combination of both. Soft tissue etiology include incompetent lips, which can be associated with proclined upper incisors, a lower lip trap behind the upper incisors, which can lead to proclination of upper incisors and retroclination of lower incisors, and various tongue habits which contribute to the malocclusion.

There are common features to individuals with Class II Division 1 malocclusions that involve skeletal, dental, and soft tissue manifestations of the affected individuals. Skeletal features include a discrepancy between the maxillary and mandibular jaws that diagnostically present with a larger ANB cephalometric angle (ANB≥5), as well as a variety of different types of bites in the vertical axis ranging from open to deep. The dental features which are common include an Angle Class II molar relationship that is 50% or greater Class II, Class II canine relationship, proclined maxillary incisors, an increased overjet, and vertical dental relationships ranging from open to deep bite.

Successful treatment of a patient with Class II Division 1 malocclusion involves several factors in the management strategies including etiology, amount of growth potential, severity, and facial profile of the patient. Several treatment modalities exist for Class II correction, such as selective extraction therapy, growth modification, which includes head-gear and functional appliances, fixed appliances with intermaxillary Class II elastics, removable appliances, and orthognathic surgery.

2.4.2 MARA (Mandibular Anterior Repositioning Appliance)

Figure 1a. Functional components of the Mandibular Anterior Repositioning Appliance (MARA

Figure 1b. Clinical photo with MARA

The MARA (AOA, Sturtevant, Wisconsin, USA) is a functional appliance used for the correction of Class II malocclusions. Functional appliances are referred to as appliances that are removable or fixed and are designed for growth modification in growing patients. Class II functional appliances are used for correction of mild to moderate Class II Division 1 Malocclusions with average or reduced lower facial height. The MARA, when used according to original design, can be used together with fixed appliances or after a few months of active treatment. It contains no continuous upper arch-lower arch connection and is rigid. Its design resembles an inclined plane serving as an obstacle that is to be avoided during closure, thus encouraging the lower jaw to move forward. This forced movement is supposed to induce a neuromuscular re-education while correcting the Class II dentoskeletal relationships. Attachments are only required on the first molars and allows for concurrent use of other appliances including fixed appliances, transpalatal arches, and rapid maxillary expanders, in order to better address the specific needs of the patient and increase treatment efficiency. A recommended treatment time of at least 12 months is required to achieve an orthopaedic effect (Toll et al., 2010).

MARA is one of the few fixed functional appliances that requires no compliance and can be used concomitantly with full fixed appliances while skeletal correction is being achieved. This allows for efficient and effective Class II treatment increasing successful treatment outcomes. The treatment effects and changes produced of the MARA in patients with Class II skeletal malocclusions has been previously studied by Pangrazio et al. (2012). Restriction of maxillary growth and no significant mandibular growth were observed with the use of the MARA. The Class II correction was obtained primarily by mesial migration of the lower molars, flaring of the lower incisors, and slight maxillary molar distalization, which was determined by measuring the mesial movement of the of the lower molars (L6-Crown-symphysis), mandibular incisor to the mandibular plane angle (IMPA), and measuring the anterior-posterior displacement of the maxillary molars compared to controls, respectively. There was no vertical effect and no significant effect on mandibular growth observed in using the MARA appliance. These findings are similar to those reported in other studies with functional appliance therapy, such as the Herbst.

2.5 Two-Dimensional Analysis

2.5.1 Panoramic X-rays

Panoramic radiographs have traditionally been used for orthodontic treatment during the initial, progress, and final stages of orthodontic treatment for diagnosis, monitoring of root resorption and third molar development, and to finalize the angulations of the teeth (Mayoral, 1982; Ursi et al., 1990). Previous studies have shown that panoramic radiographs are a reliable indicator evaluating third molar positions in two dimensions only (Olive and Basford, 1981; Larheim and Svannes, 1986). This only allows us to see the mesio-distal angulation of the mandibular third molars. However, panoramic radiographs have distortions that do not reflect the true 3-dimensional teeth angulations because the x-ray beam is not orthogonal to the target teeth (McKeel et al., 2002; Garcia-Figueroa et al., 2008).

2.5.2 Lateral Cephalograms

Current techniques to understanding the effects of tooth movement in vertical and antero-posterior planes is derived primarily by the use of lateral cephalograms taken at separate time points, and then superimposed using stable anatomic landmarks (Björk, 1968). This method allows the provider an estimation of skeletal and dental change during the period of evaluation. However, there are several limitations using serial cephalometric superimpositions. First, anatomic landmarks are often difficult to be reliably identified due to the overlapping of the left and right structures of the craniofacial region. Furthermore, inconsistent positioning of the lateral cephalogram between the serial radiographs cannot only affect the overlap, but further skew measurements due to the complications of superimposing the films on the stable structures. A study by Ghafari et al. (1998) describes the misinterpretation of growth and treatment outcomes by serial cephalograms concluding that reliability of cephalometric superimposition is also compromised by the method's susceptibility to unnoticed difference in the stable reference structures. Since the treatment changes of interest can be relatively minute compared to the error of the cephalometric method, precise analysis to estimate tooth movement is extremely difficult (Jones, 1991).

2.6 Three-Dimensional Analysis

Tooth position and changes are traditionally analyzed in 2-dimensional radiographs, but the positional and angulation changes are 3-dimensional in nature. The recent shift towards the use of cone-beam computer tomography (CBCT) in orthodontics has allowed the visibility of the entire tooth crown and roots in three dimensions. A study which constructed 2-dimensional projections of panoramic images rendered from 3-dimensional CBCT images in order to measure angulations in teeth compared these measurements to a gold-standard 3-dimensional measuring device concluded the constructed images might be better than conventional panoramic radiographs in assessing root angulations, although the measurements were still not representative and significantly different from the true root angulations (Van Elsande et al., 2010). Measurement of the mesiodistal angulation and faciolingual inclination of teeth requires 3-dimensional images especially during tooth formation when teeth are still undergoing development such as the third molars. The three-dimensional volumetric renders obtained from

CBCT scans demonstrate the dentofacial structures in a 1:1 ratio and distortions are clinically insignificant (Lascala, 2004; Hutchinson, 2005; Lagravere et al., 2008).

3. MATERIALS AND METHODS

3.1 Sample

To conduct the study, initial and final records of 500 subjects with Class II Division 1 malocclusion and Class I malocclusiona treated at Jacobson and Tsou Orthodontics, a private practice located in Chicago, Illinois, were assessed. The subjects were then organized into two electronic file folders based on diagnosis, and then inclusion and exclusion criteria were applied within each folder. Those subjects who met the inclusion criteria were then randomly assigned a code obtained from a randomization table. Subjects who met the criteria for the experimental group had their initial and final CBCT images then placed in the electronic file folder which was assigned a code. Class I malocclusion subjects who met the inclusion criteria were used in the study as the control group.

The initial and final CBCT images were de-identified by the office personnel. The descriptive information included: age at beginning of treatment, gender, length of treatment, % Class II on the left, % Class II on the right, bracket slot size, type of treatment and appliances used. The diagnostic treatment summaries included: problem list, mechanics, and treatment sequence. Information was gathered and documented on the corresponding form. The files were then saved in DOC (document) file format and saved into its respective folder with the de-identified CBCT images. The individual files were identified with the code provided by the office personnel. Each coded folder contained the following content: initial CBCT image, final CBCT image, a document containing descriptive information, and a document containing diagnostic treatment summary.

There was no information that made possible the re-identification and the coded folders were made available to the principalle investigator and members of the research committee. The master re-identification key was kept by the office personnel and was not accessed throughout the duration of the research study. Upon successful completion of the study, the master re-identification key was destroyed by the office personnel.

3.2 Study Methodology

3.2.1 Study Design and Data Acquisition

In this retrospective study, the mandibular third molar position and angulation will be compared pre-treatment and post-treatment within the same patients with Class II division 1 malocclusions. The Class II malocclusion group will have been treated with an orthopedic functional appliance, the MARA. Both the experimental and control group will have the mandibular third molar position and angulation compared pre-treatment to post-treatment. Comparison of pre-treatment and post-treatment changes will be compared between the groups, as well as pre-treatment to post-treatment within the same subject between the left mandibular third molar and the right mandibular third molar.

The de-identified, coded folders and their contents were examined by the principal investigator to verify the suitability of the subjects according to the inclusion and exclusion criteria, which are listed in section 3.6.

The CBCT scans were used for the evaluation of (1) mandibular third molar displacement in three planes of space, (2) mandibular third molar angulation measured in three planes of space, and (3) the total distance on both the left and right mandibular third molars of each subject. The initial and final CBCT images were then imported into Invivo 5 Dental (Anatomage, San Jose, CA) Software to define landmarks and the construction of reference planes.

3.2.2 Inclusion and Exclusion Criteria

For the purposes of this study, criteria to classify a Class II Division 1 malocclusion subject was defined as an Angle Class II molar relationship of at least 50% bilaterally. All subjects included in the study had all treatment records available including pre- and post-treatment intraoral and extra oral photographs of the dentition, pre- and post-treatment digital models, pre- and post-treatment CBCT images, and diagnostic and treatment record notes. All cases were treated into an Angle Class I molar relationship. Any cases debonded early prior to achieving an ideal occlusion were also excluded from the sample.

All subjects from both the experimental and control group were treated with fixed appliance with the addition of the MARA functional appliance for the experimental group. Pretreatment comparison of both groups showed no statistically significant difference between them regarding age and sex variable. The ages of the subjects in both groups were matched to eliminate the difference in growth occurring on intergroup comparisons. The Control group consisted of subjects that were skeletal Class I (ANB, 0-4), with a normal facial vertical growth pattern and mild or no crowding in the mandibular arch (≤ 3mm).

Inclusion Criteria

Patients who met the following criteria were included in this study.

1. Bilaterally unerupted mandibular third molars visible on CBCT in mesioangular position. Not more than two thirds of root development of the third molars had taken place.
2. Bilateral Dental Class I or Class II division 1 malocclusion according to molar position
3. Non-extraction treatment
4. MARA appliance used for Class II division 1 malocclusion
5. High-quality pretreatment and posttreatment CBCT without any magnification and distortion errors.

Exclusion Criteria

Patients who met the following exclusion criteria were not included in this study.

1. Cases requiring extraction therapy
2. Previous history of orthognathic surgical treatment
3. Previous extraction or missing permanent teeth.
4. Agenesis of third molars in maxilla or mandible
5. Developmental anomalies.
6. Poor quality CBCT
7. Non-confirmed third molar radiographically
8. Supernumerary molar present

3.2.3 CBCT Image Acquisition

CBCT devices utilized in both offices are from the same manufacturer (i-CAT; Imaging Sciences International, Hatfield, Pa). Two sets of full head CBCT scans were obtained following a standardized protocol (120 kV, 5 mA, 13 3 17-cm field of view, 0.4-mm voxel, and 20-second scanning time). The machine is equipped with a sitting chair and head support so that the patient is scanned while in an upright position. CBCT scans were taken while participants were sitting in an upright position ensuring natural head position, achieved utilizing a mirror and laser beam light. Participants were also instructed to rest the tongue in a relaxed position touching the front teeth, breathe lightly through their noses, avoid deglutition and position the mandible in maximum inter-digitation (centric occlusion).The images were saved in a DICOM (Digital Imaging and Communications in Medicine) format.

3.2.4 Mandibular Segmentation and 3D Reconstruction

The de-identified CBCT scans were mailed to Department of Orthodontics, College of Dentistry, University of Illinois at Chicago, were in DICOM format. The scans were imported into Dolphin 3D (version 11.7, Dolphin Imaging, Chatsworth, CA).

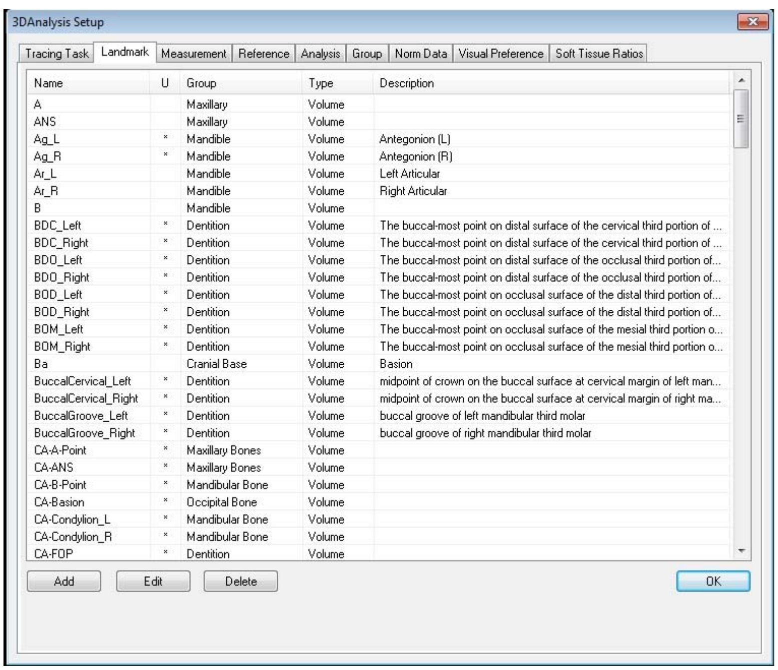
3.3 Invivo 5 Dental Software

Invivo 5 Dental (Anatomage, San Jose, CA) is an industry leading developer in advanced 3D rendering software for both medical and dental fields for more than 10 years. Anatomage developed Invivo 3D imaging software that aids in medical and dental radiology diagnosis in the standard DICOM format. The software offers versatile radiology layouts for implant assessment, TMJ workups, sinus examination, airway analysis, and cephalometric tracing. Traditional panoramic and cephalometric images can be created from volumetric reconstructions. The 3D Analysis feature is specific to Invivio 5 and proved to be essential to the analysis.

Orthodontic applications of Invivo 5 include more diagnostic information and digital capabilities. 3D scans allow orthodontists to quickly analyze patient malocclusion, transpalatal width, and molar angulation. Pertinent to our study, the 3D Analysis tool of the Invivo 5 software expands the capabilities of Invivo 5 with accurate and unambiguous 3D cephalometric tracing. A comprehensive analysis library and assisted landmark identification is provided for ease of use. Few studies previously used this study design. Therefore this program was needed to create a custom analysis. A custom analysis can be defined by the operator which was the basis for the measurements carried out in the study.

3.4 Landmark Identification

The identification of landmarks is required in order to establish the coordinate system and reference planes for the custom analysis. Landmark identification is a function of the 3D analysis of Invivo5 Dental software. The landmarks identify points in the mandible that are not altered by growth or orthodontic treatment. The landmarks will create a reference plane that allow the changes in distance and angulation to be observed. Landmarks are unique variables and are customized by assigning user defined names. Landmarks were created using landmarks tab of the "settings" function which appears as the icon  which will display the table in Figure 2.



Name	U	Group	Type	Description
A		Maxillary	Volume	
ANS		Maxillary	Volume	
Ag_L	*	Mandible	Volume	Antegonion (L)
Ag_R	*	Mandible	Volume	Antegonion (R)
Ar_L		Mandible	Volume	Left Articular
Ar_R		Mandible	Volume	Right Articular
B		Mandible	Volume	
BDC_Left	*	Dentition	Volume	The buccal-most point on distal surface of the cervical third portion of ...
BDC_Right	*	Dentition	Volume	The buccal-most point on distal surface of the cervical third portion of ...
BDO_Left	*	Dentition	Volume	The buccal-most point on distal surface of the occlusal third portion of...
BDO_Right	*	Dentition	Volume	The buccal-most point on distal surface of the occlusal third portion of...
BOD_Left	*	Dentition	Volume	The buccal-most point on occlusal surface of the distal third portion of...
BOD_Right	*	Dentition	Volume	The buccal-most point on occlusal surface of the distal third portion of...
BOM_Left	*	Dentition	Volume	The buccal-most point on occlusal surface of the mesial third portion o...
BOM_Right	*	Dentition	Volume	The buccal-most point on occlusal surface of the mesial third portion o...
Ba		Cranial Base	Volume	Basion
BuccalCervical_Left	*	Dentition	Volume	midpoint of crown on the buccal surface at cervical margin of left man...
BuccalCervical_Right	*	Dentition	Volume	midpoint of crown on the buccal surface at cervical margin of right ma...
BuccalGroove_Left	*	Dentition	Volume	buccal groove of left mandibular third molar
BuccalGroove_Right	*	Dentition	Volume	buccal groove of right mandibular third molar
CA-A-Point	*	Maxillary Bones	Volume	
CA-ANS	*	Maxillary Bones	Volume	
CA-B-Point	*	Mandibular Bone	Volume	
CA-Basion	*	Occipital Bone	Volume	
CA-Condylion_L	*	Mandibular Bone	Volume	
CA-Condylion_R	*	Mandibular Bone	Volume	
CA-FOP	*	Dentition	Volume	

Figure 2. Landmarks of the settings enabled the user to add, edit, and delete landmarks. Nomenclature reflected the landmarks needed for the principal investigator to anatomically identify.

3.4.1 The Mandibular Plane

The landmarks for the reference Mandibular Plane (MS, CLeft, CRight) were defined using the "Add" function within the setup function:

MS = the inner contour of the cortical plate at the lower border of the symphysis on the midline

CLeft = the upper-most contour of the mandibular foramen at the posterior aspect on the left

CRight = the upper-most contour of the mandibular foramen at the posterior aspect on the right

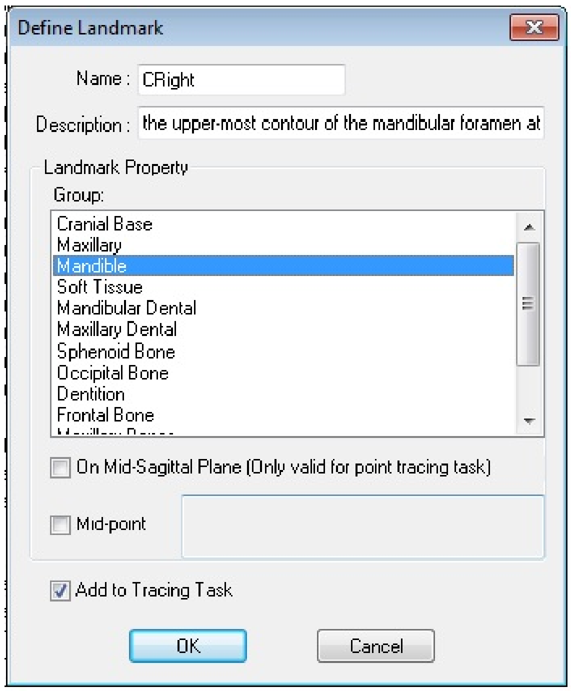


Figure 3. The landmark for CRight, the upper-most contour of the mandibular foramen at the posterior aspect on the right is defined by assigning a name, description, and a group for the landmark property. In the case for CRight, the group assigned is the mandible and it will be assigned to the tracing task to require the user to identify the landmark when tracing.

Once the landmarks were assigned variable names, they were added to the current tracing list and used in the tracing task. The tracing task is the feature that allowed the user to identify the landmarks selected from the available tracing features. From the list of available tracing features, the landmarks for the reference mandibular plane were selected to the current tracing list seen in Figure 4.

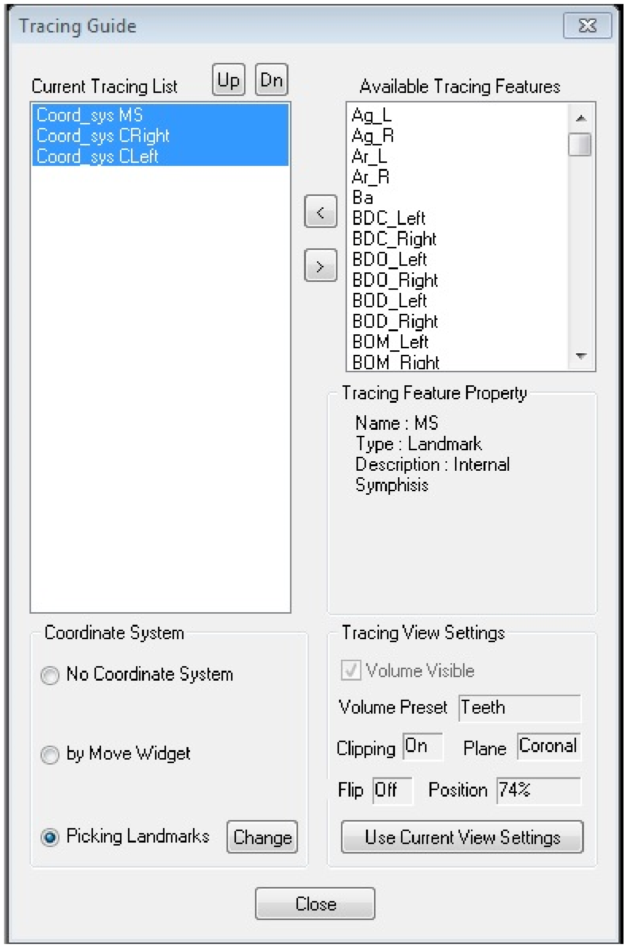


Figure 4. The landmarks for the stable mandibular plane were added to the current tracing list and are now part of tracing task.

"Create Tracing" feature initiated the tracing task and prompted the identification of the landmarks once "Start" was selected as shown in Figure 5. The landmarks were then identified by the user as demonstrated in Figures 6, 7, 8.

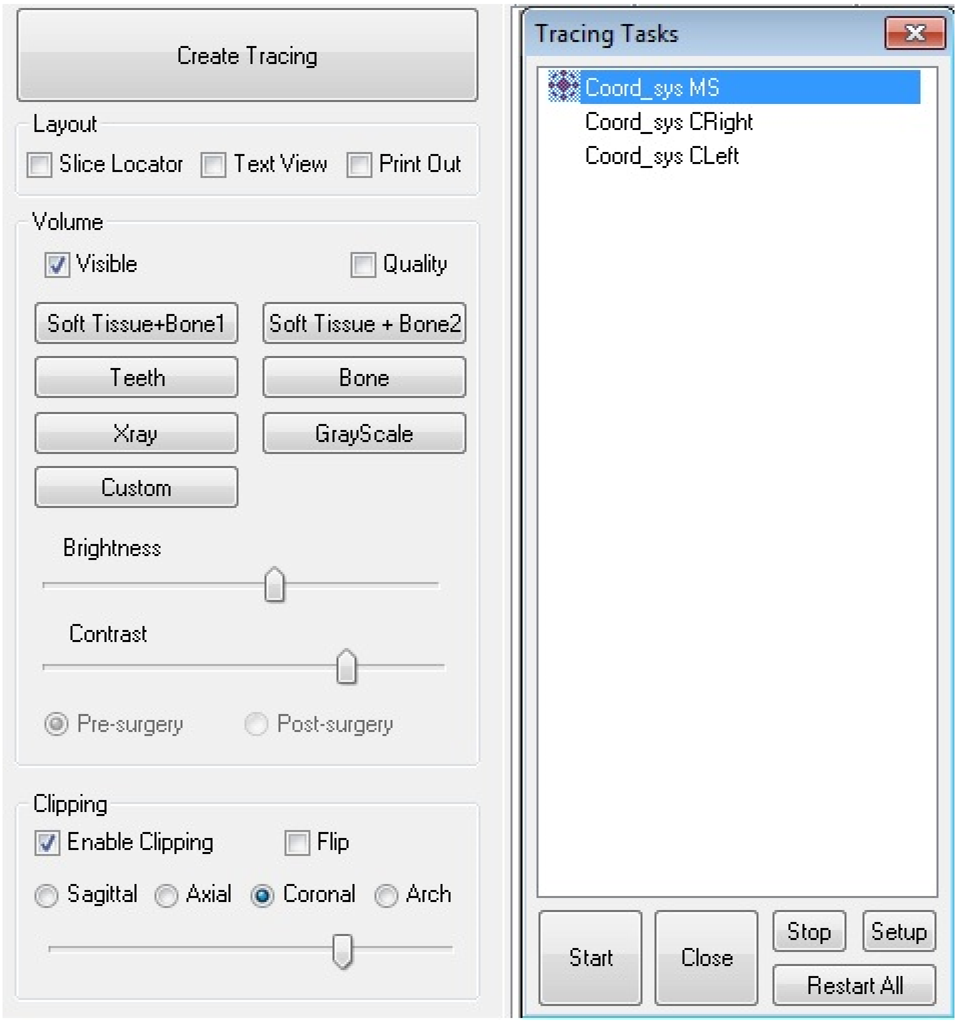


Figure 5. Once "Create Tracing" has been selected, the user is prompted to initiate the tracing task. Upon selecting "Start" the user will be guided to select the landmarks for the tracing task.

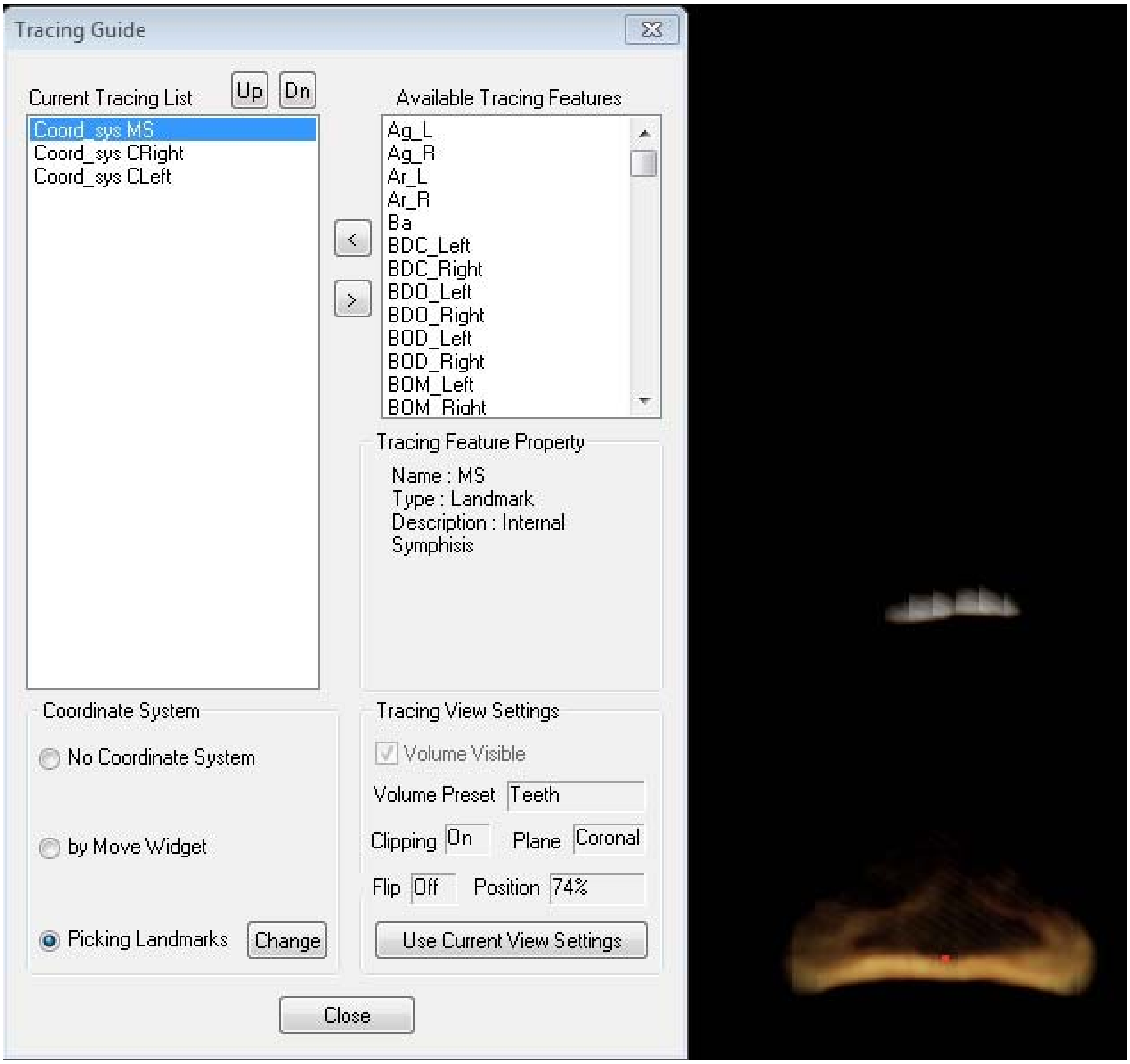


Figure 6. The landmark MS is identified by the user as the inner contour of the cortical plate at the lower border of the symphysis on the midline.

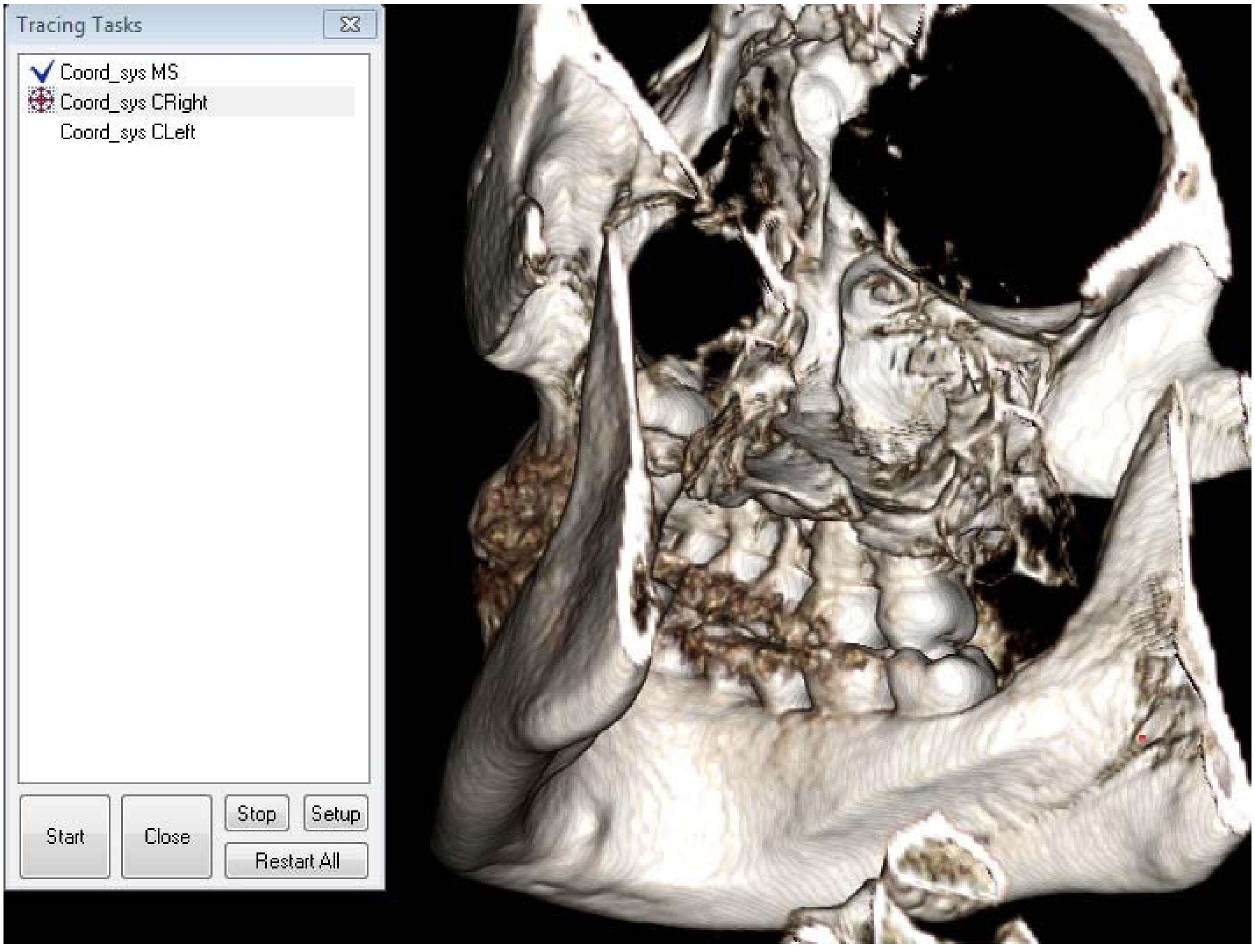


Figure 7. The landmark CRight was identified by the user as the upper-most contour of the mandibular foramen at the posterior aspect on the right.

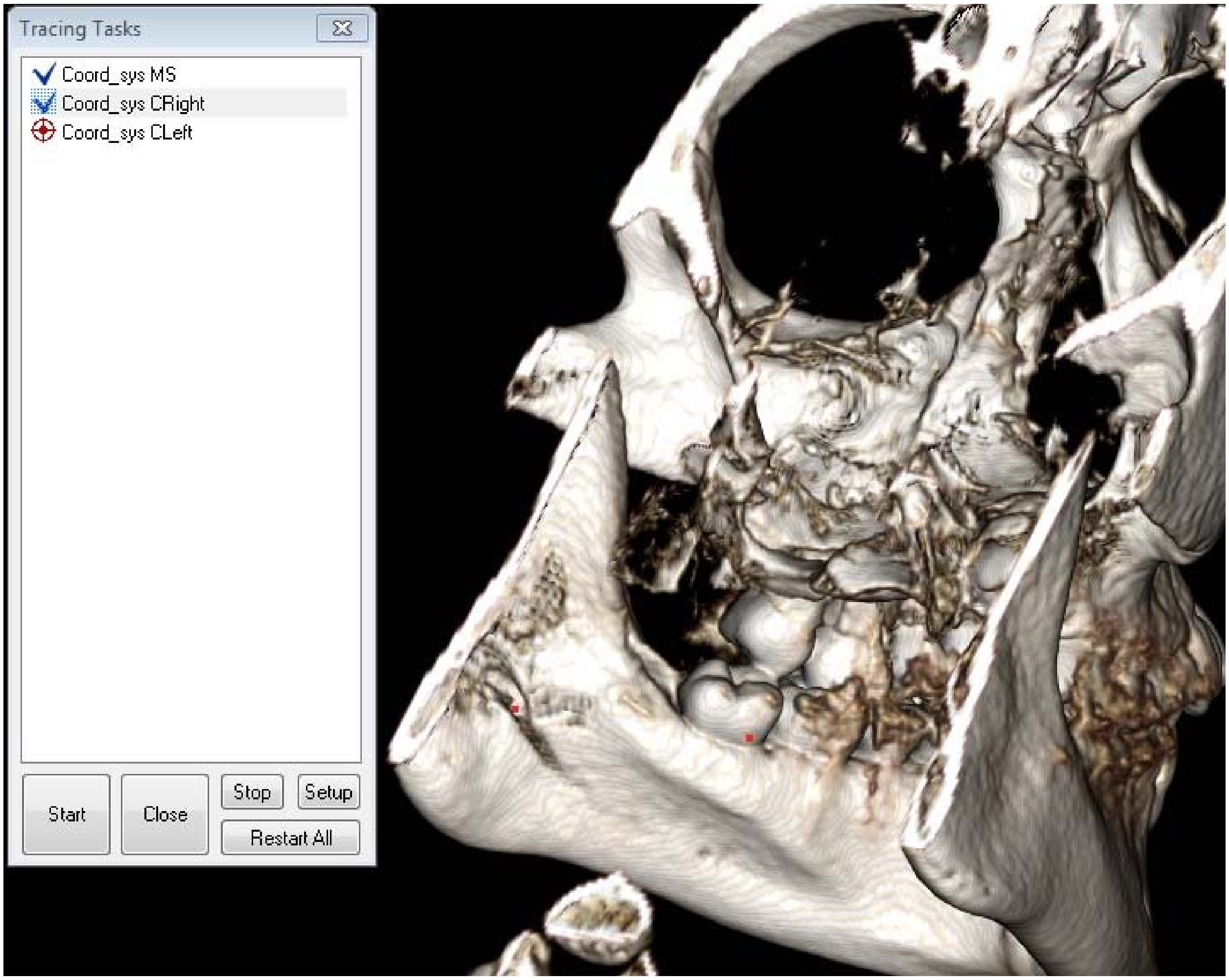


Figure 8. The landmark CLeft was identified by the user as the upper-most contour of the mandibular foramen at the posterior aspect on the left.

Functions on the sidebar made possible the accurate identification of landmarks. For example, the volume, brightness, contrast, and clipping made possible precise identification of landmarks in the tracing task. CLeft and CRight in this example were best viewed using "Bone" as the volume in contrast to MS, which was best viewed used using the "Teeth" volume. A combination of adjustments ensured the accurate identification of the landmark, MS, to be in the center of the midline and at the lower border of the internal symphysis. Landmark identification was verified from anterior, lateral, and vertical aspects to ensure accurate identification. Once these three landmarks were identified, the tracing task was complete and the reference planes and coordinate system can be designed for the analysis.

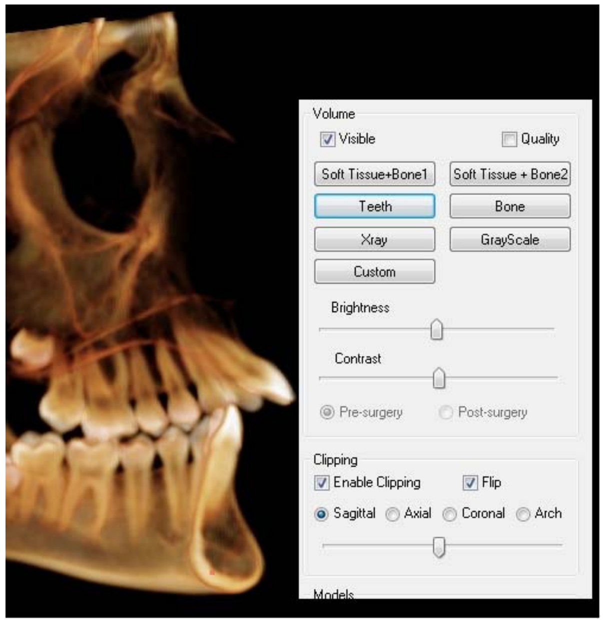


Figure 9. The tooth volume, brightness, and contrast were adjusted to ensure proper identification of MS. Sagittal clipping feature was also used to section the image along the mid-sagittal plane to remove all teeth right of the midline to ensure the landmark, MS, was accurately displayed in the center.

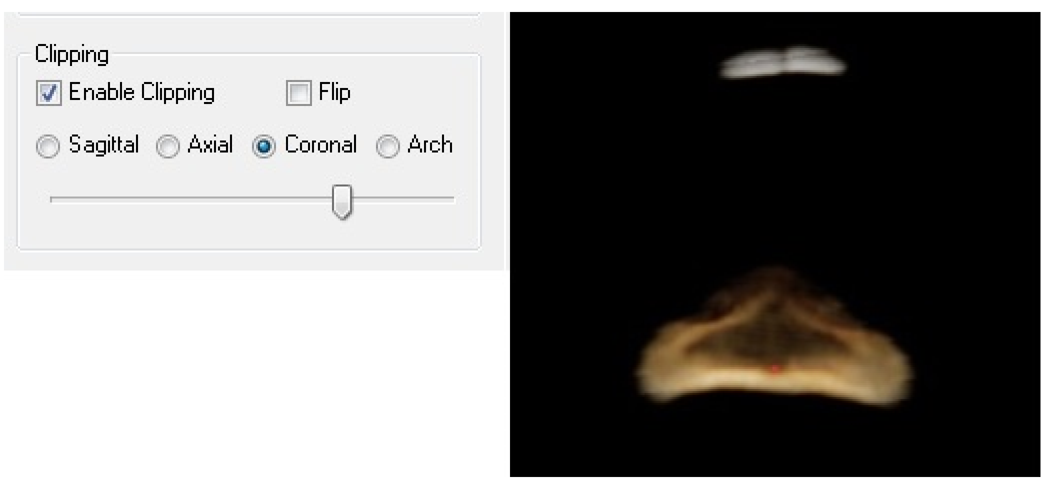


Figure 10. The Clipping feature was used to clip the image in coronal segments which enabled alternate views of MS from various slices to ensure the point was accurately identified in three dimensions of space.

Figure 11. Adjustments to brightness, contrast, and clipping features were applied allowing visualization of the precisely identified landmark, MS.

3.5 Construction of Reference Planes

To construct the reference planes, a defined coordinate system was required. The coordinate system setup icon  defined the coordinate system by selecting the option "Picking Landmarks". The origin of the coordinate system was defined as the midpoint of the previously identified landmarks, CRight and CLeft, and was assigned the name Midpoint_CLeft_CRight. Figure 12 demonstrates how variable names were defined.

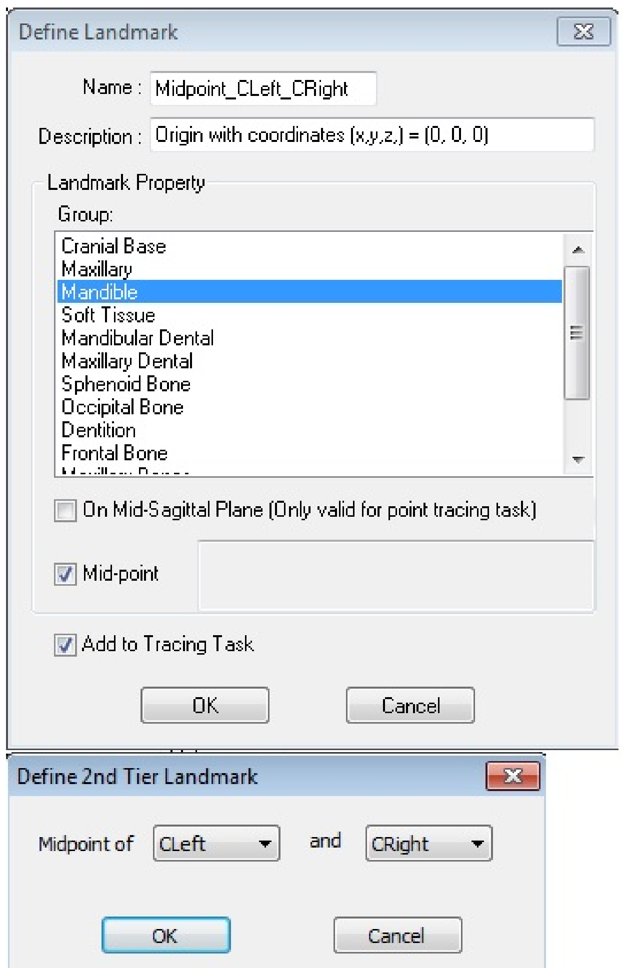


Figure 12. The variable name of the origin of the coordinate system, Midpoint_CLeft_CRight, corresponded to the calculated midpoint of the previously defined mandibular landmarks, CRight, and CLeft.

To define the coordinate system, the coordinate system setup icon  was selected which prompted the user set up the coordinate system. This analysis defined the coordinate system selecting the options “by Picking Landmarks” and selecting “Change” which prompted landmarks to be selected by the user.

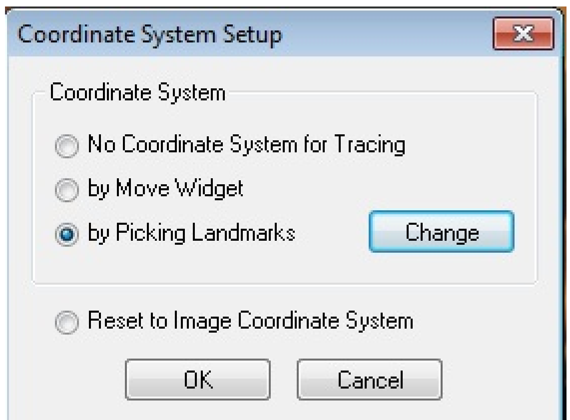


Figure 13. The coordinate system setup has three options to define coordinate system used. This analysis picked landmarks to define the coordinate system.

3.5.1 The Mandibular, Mid-sagittal, and Coronal planes

For our analysis, landmarks were picked which were previously defined allowing for consistency in the origin of the coordinate system and reference planes, which remained identical throughout the analysis.

In Figure 14, the “Change” option was selected, which guided through the following sequence:

Step 1. Origin: Origin Landmark = Midpoint_CLeft_Cright

Step 2. “Horizontal Plane oriented Coordinate System” was selected.

Step 3. “Use 3 Points” was defined with the following landmarks:
Landmark 1 = CLeft, Landmark 2 = CRight, Landmark 3 = MS

Step 4: The axis for the Perpendicular Plane was defined by selecting “Define A-P Axis (Mid-Sagittal Plane) with the following landmarks:
Landmark 1 = Midpoint_CLeft_Cright, Landmark 2 = MS

Step 5. L-R Axis (Frontal Plane) was defined with the following landmarks:
Landmark 1 = CRight, Landmark 2 = CLeft

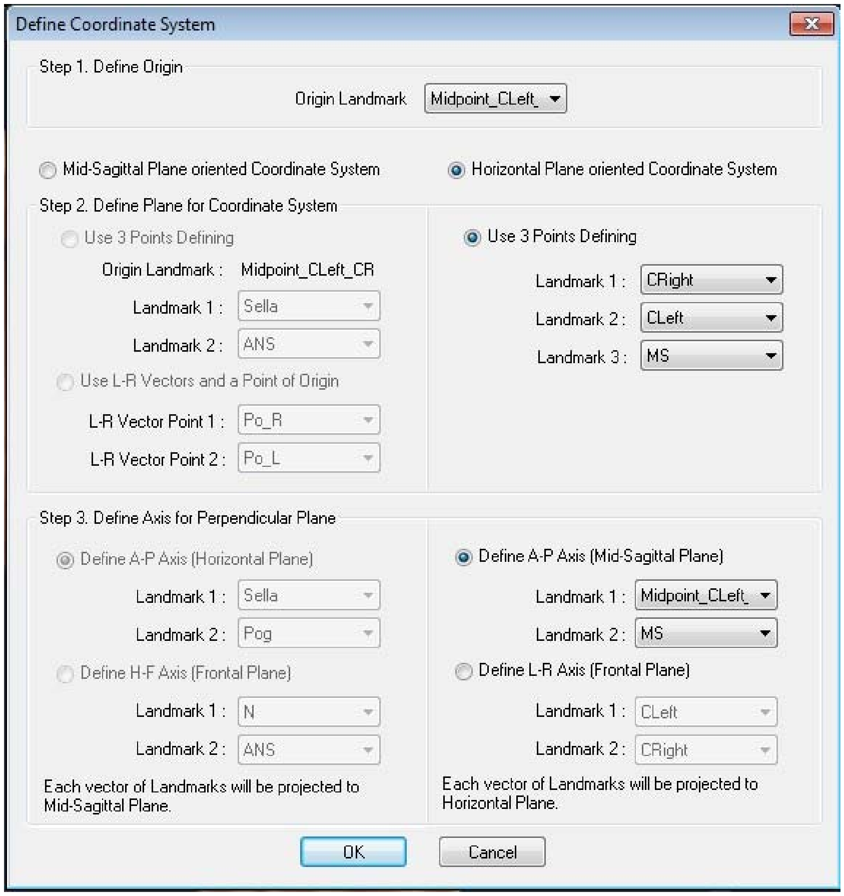


Figure 14. The coordinate system for this table displayed the orientation and allowed the user to identify the origin landmark with coordinates (0, 0, 0). The origin was identified as the midpoint between the stable points CLeft and CRight, Midpoint_CLeft_CRight.

The stable mandibular horizontal axial plane was defined in previous study (González et al., 2016). The plane was defined passing through the three most stable structures of the mandibular body: the upper-most contour of the mandibular foramen at the posterior aspect on the right (CRight) and the left (CLeft) and the inner contour of the of the cortical plate at the lower border of the symphysis on the midline (MS) as demonstrated in Figure 15.The coronal plane was defined as being perpendicular to the mandibular axial plane while passing through CRight and CLeft. The mid-sagittal plane was defined as being perpendicular to both the mandibular axial plane and the coronal plane while passing through Midpoint_CLeft_Cright and MS.

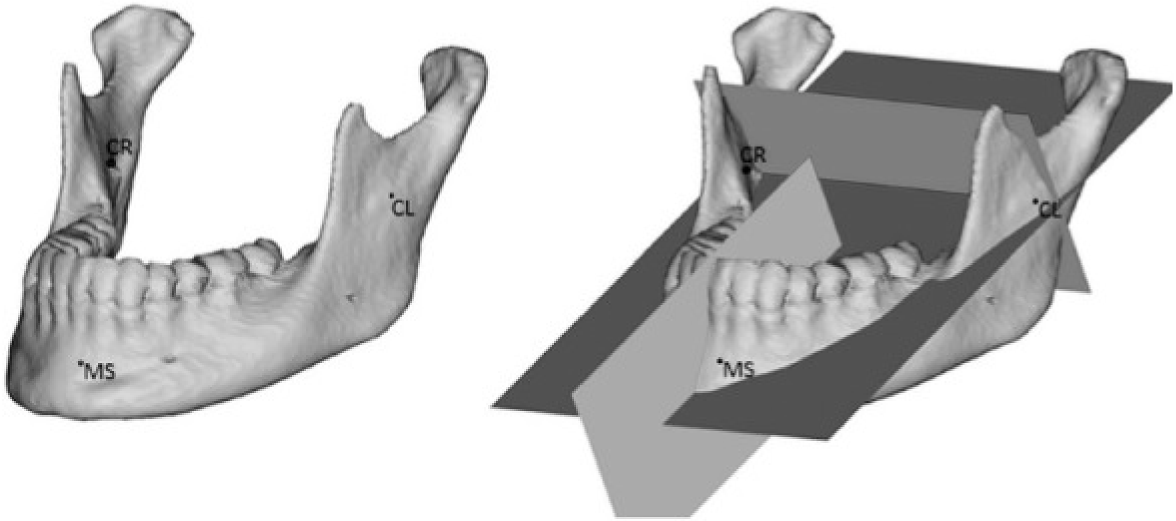


Figure 15. The three stable mandibular structures CR, CL, and MS can be visualized. The constructed stable mandibular reference plane passes through the three stable structures defined in the previous study (González, 2016).

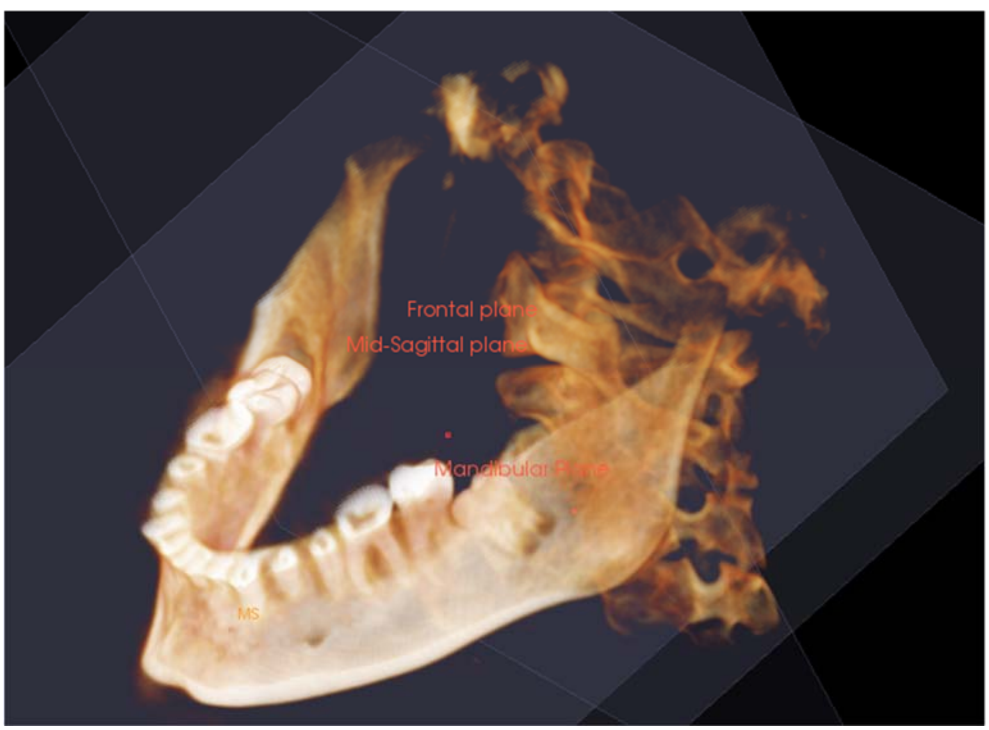


Figure 16. The Mandibular plane is the horizontal reference plane passing through CRight, CLeft, and MS. The Mid-Sagittal plane passes through MS and Midpoint_CLeft_CRight and is perpendicular to the Mandibular plane. The Frontal (coronal) plane passes through CRight and CLeft and is perpendicular to the Mandibular plane and Mid-Sagittal plane.

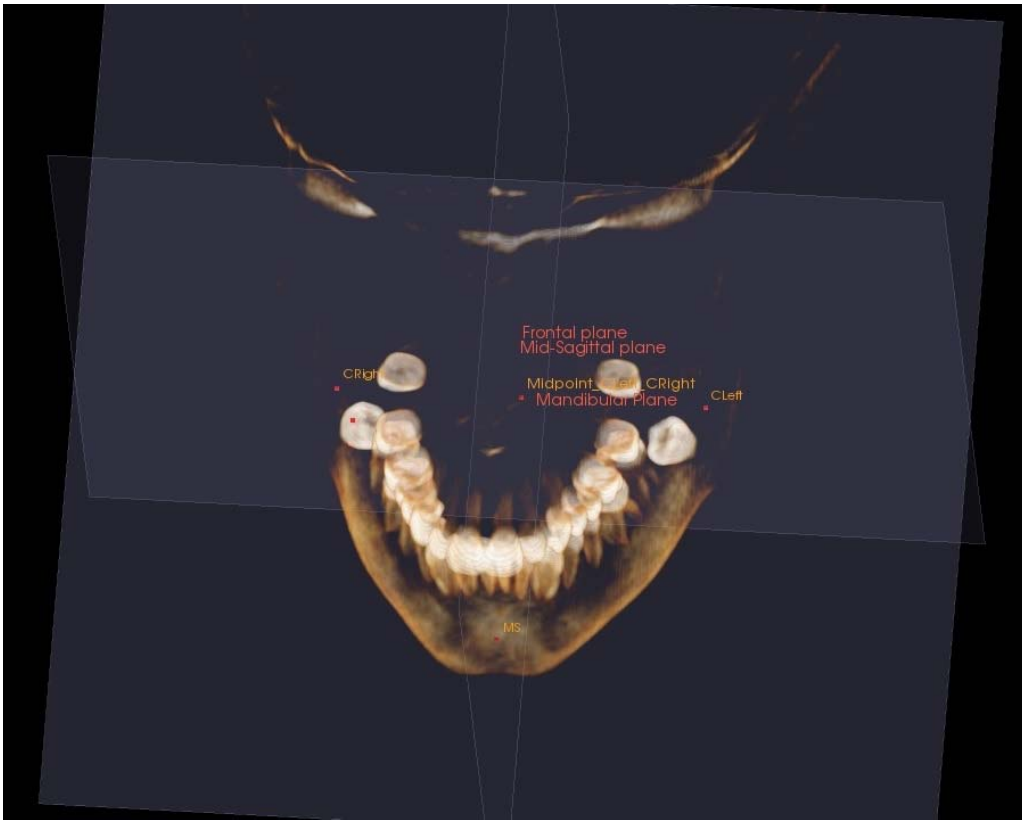
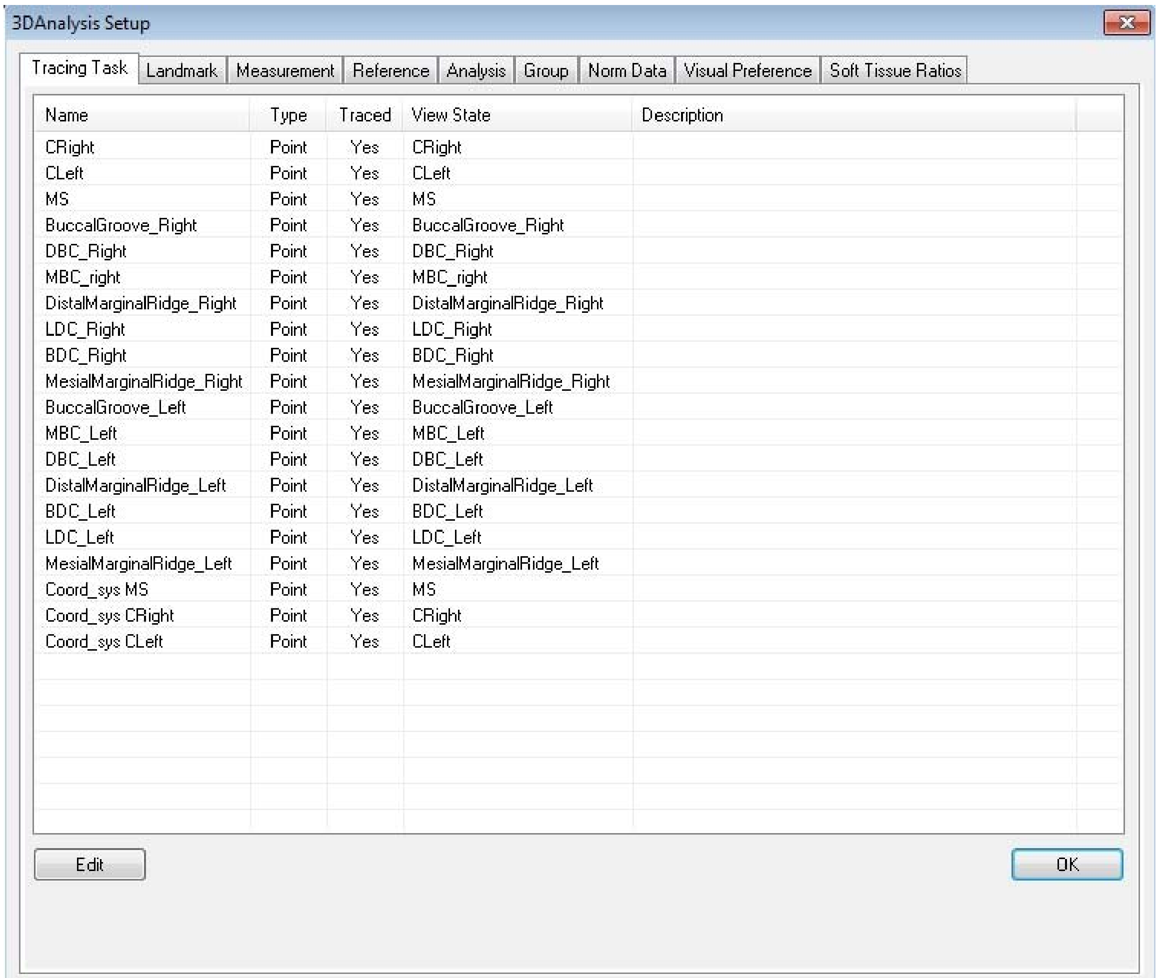


Figure 17. An alternate view of the three constructed planes orthogonal to one another and the origin, Midpoint_CLeft_CRight.

3.6 Landmark Identification for Third Molars

The landmarks for the third molars were defined using the “Add” function within the landmark tab of the setup function and were assigned to the “Dentition” group. Once all landmarks to be identified were added, the tracing task included landmarks identified on the mandible as well as the dentition as in Figure 18.



Name	Type	Traced	View State	Description
CRight	Point	Yes	CRight	
CLeft	Point	Yes	CLeft	
MS	Point	Yes	MS	
BuccalGroove_Right	Point	Yes	BuccalGroove_Right	
DBC_Right	Point	Yes	DBC_Right	
MBC_right	Point	Yes	MBC_right	
DistalMarginalRidge_Right	Point	Yes	DistalMarginalRidge_Right	
LDC_Right	Point	Yes	LDC_Right	
BDC_Right	Point	Yes	BDC_Right	
MesialMarginalRidge_Right	Point	Yes	MesialMarginalRidge_Right	
BuccalGroove_Left	Point	Yes	BuccalGroove_Left	
MBC_Left	Point	Yes	MBC_Left	
DBC_Left	Point	Yes	DBC_Left	
DistalMarginalRidge_Left	Point	Yes	DistalMarginalRidge_Left	
BDC_Left	Point	Yes	BDC_Left	
LDC_Left	Point	Yes	LDC_Left	
MesialMarginalRidge_Left	Point	Yes	MesialMarginalRidge_Left	
Coord_sys MS	Point	Yes	MS	
Coord_sys CRight	Point	Yes	CRight	
Coord_sys CLeft	Point	Yes	CLeft	

Figure 18. The tracing tasks list displayed the name of landmark identified, the type, status, and the viewing state of the landmark.

The dentition landmarks were assigned names according to the anatomical landmark, tooth surface, and the side of the mandible. Figures 19-25 illustrate the anatomical landmarks that were identified during the tracing task of the third molar on the right side. The left third molar used identical nomenclature and landmarks to the right third molar and were subsequently completed during the tracing task. The completed tracing task of the right third molar on the buccal, distal, and occlusal surfaces can be seen in Figures 26, 27, and 28.

RIGHT MOLAR

BuccalGroove_Right = the buccal groove of right mandibular third molar (Figure 19)

DBC_Right = the most distal point of the right mandibular third molar on the buccal surface at the cervical margin (Figure 20).

MBC_Right = the most mesial point of the right mandibular third molar on the buccal surface at the cervical margin (Figure 21).

DistalMarginalRidge_Right = lowest depression on the distal marginal ridge on the right mandibular third molar (Figure 22).

LDC_Right = the most lingual point of the right mandibular third molar on the distal surface at the cervical margin (Figure 23).

BDC_Right = the most buccal point of the right mandibular third molar on the distal surface at the cervical margin (Figure 24).

MesialMarginalRidge_Right = lowest depression on the mesial marginal ridge on the right mandibular third molar (Figure 25).

Figure 19. The identified landmark is the buccal groove of the right third molar, BuccalGroove_Right, identified during the tracing task.

Figure 20. The identified landmark is the most distal point of the right mandibular third molar on the buccal surface at the cervical margin, DBC_Right, identified during the tracing task.

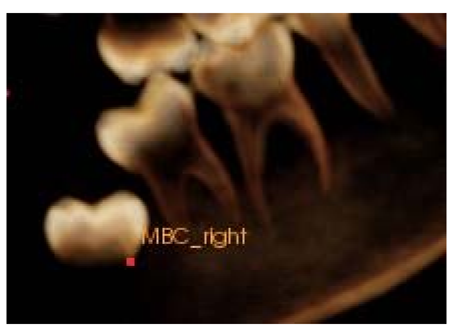


Figure 21. The identified landmark is the most mesial point of the right mandibular third molar on the buccal surface at the cervical margin, MBC_Right, identified during the tracing task.

Figure 22. The identified landmark is the distal marginal ridge of the right third molar, DistalMarginalRidge_Right, identified during the tracing task.

Figure 23. The identified landmark is the most lingual point of the right mandibular third molar on the distal surface at the cervical margin, LDC_Right, identified during the tracing task.

Figure 24. The identified landmark is the most buccal point of the right mandibular third molar on the distal surface at the cervical margin, BDC_Right, identified during the tracing task.

Figure 25. The identified landmark is the distal marginal ridge of the right third molar, DistalMarginalRidge_Right, identified during the tracing task.

LEFT MOLAR

BuccalGroove_Left = buccal groove of left mandibular third molar.

DBC_Left = the most distal point of the left mandibular third molar on the buccal surface at the cervical margin.

MBC_Left = the most mesial point of the left mandibular third molar on the buccal surface at the cervical margin.

DistalMarginalRidge_Left = lowest depression on the distal marginal ridge on the left mandibular third molar.

LDC_Left = the most lingual point of the left mandibular third molar on the distal surface at the cervical margin.

BDC_Left = the most buccal point of the left mandibular third molar on the distal surface at the cervical margin.

MesialMarginalRidge_Left = lowest depression on the mesial marginal ridge on the left mandibular third molar.

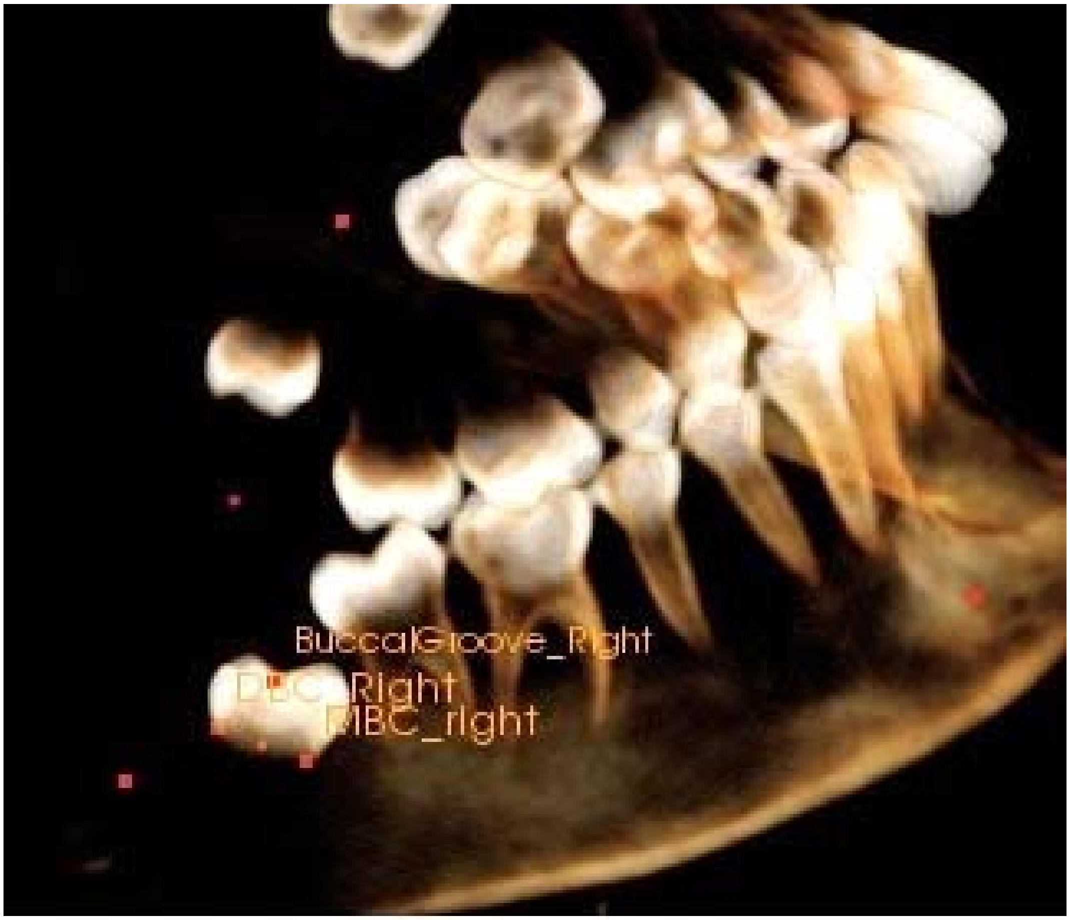


Figure 26. The three landmarks on the buccal surface of the right third molar were identified during the tracing task. The buccal groove of right mandibular third molar, BuccalGroove_Right, the most distal point of the right mandibular third molar on the buccal surface at the cervical margin, DBC_Right, and the most mesial point of the right mandibular third molar on the buccal surface at the cervical margin, MBC_Right.

Figure 27. The three points on the distal surface of the right third molar were identified during the tracing task. The distal marginal ridge of right mandibular third molar DistalMarginalRidge_Right, the most lingual point of the right mandibular third molar on the distal surface at the cervical margin LDC_Right, and the most buccal point of the right mandibular third molar on the distal surface at the cervical margin, BDC_Right.

Figure 28. The distal marginal ridge of right mandibular third molar, DistalMarginalRidge_Right, was identified previously during the distal surface portion of the tracing task. The mesial marginal ridge of right mandibular third molar, MesialMarginalRidge_Right, was identified during the occlusal surface task.

3.7 Landmark Definition

Following the landmark identification step of the tracing task, additional landmarks were defined for use in the measurements of the analysis. These calculated landmarks are determined based on the previously identified landmarks selected during the mandibular and dentition tracing tasks completed previously. Since the calculated landmarks are defined by the landmarks identified from the tracing task, this task must be completed subsequently to the landmark identification. The list below contains the landmarks that were defined and calculated using the previously identified landmarks.

ORIGIN

Midpoint_CLeft_CRight = the midpoint of the stable mandibular points, CLeft and CRight.

This calculated point is also used to define the origin of the coordinate system for our measurements and analysis where Midpoint_CLeft_CRight (x, y, z) = (0, 0, 0). Figure 29 demonstrates the location of the origin, Midpoint_CLeft_CRight, and the landmarks which define it, CRight and CLeft.

RIGHT MOLAR

Midpoint_DBC_MBC_Right = the midpoint of the most distal point, DBC_Right, and most mesial point, MBC_Right, on the buccal surface of the right mandibular third molar at the cervical margin. In Figure 30, this point, Midpont_DBC_MBC_Right, was used to define a line, Line_yz_Right, with the buccal groove of the right mandibular third molar, BuccalGroove_Right, in order to measure the mesio-distal angular measurement in the yz-plane, Angle_yz_Right.

Midpoint_LDC_BDC_Right = the midpoint of the most lingual point, LCD_Right, and most buccal point, BCD_Right, on the distal surface of the right mandibular third molar at the cervical margin. This point, Midpoint_LDC_BDC_Right, was used to define a line, Line_xz_Right, with the distal marginal ridge of the right mandibular third molar, DistalMarginalRidge_Right, in order to measure the bucco-lingual angular measurement in the xz-plane, Angle_xz_Right, shown in Figure 31.

Midpoint_DMR_MMR_Right = the midpoint of the distal marginal ridge, DistalMarginalRidge_Right, and mesial marginal ridge, MesialMarginalRidge_Right, on the occlusal surface of the right mandibular third molar. Through Figure 32, the coordinates of this point were used to determine the displacement in three dimensions and calculate the total distance measured from the origin.

Figure 29. The origin of the coordinate systems, Midpoint_CLeft_Cright, was defined as the midpoint between CRight and CLeft.

Figure 30. The Mid_DBC_MBC_Right is the midpoint of the previously identified landmarks DBC_Right and MBC_Right and is the circular point displayed.

Figure 31. The Mid_LDC_BDC_Right is the midpoint of the previously identified landmarks LDC_Right and BDC_Right and is the circular point displayed.

Figure 32. The Midpoint_MMR_DMR_Right is the midpoint of the previously identified landmarks DistalMarginalRidge_Right and MesialMarginalRidge_Right and is the circular point displayed.

LEFT MOLAR

Midpoint_DBC_MBC_Left = the midpoint of the most distal point, DBC_Left, and most mesial point, MBC_Left, on the buccal surface of the left mandibular third molar at the cervical margin. This point, Midpont_DBC_MBC_Left, was used to define a line,Line_yz_Left, with the buccal groove of the left mandibular third molar, BuccalGroove_Left, in order to measure the mesio-distal angular measurement in the yz-plane, Angle_yz_Left.

Midpoint_LDC_BDC_Left = the midpoint of the most lingual point, LCD_Left, and most buccal point, BCD_Left, on the distal surface of the left mandibular third molar at the cervical margin. This point, Midpoint_LDC_BDC_Left, was used to define a line, Line_xz_Left, with the distal marginal ridge of the left mandibular third molar, DistalMarginalRidge_Left, in order to measure the bucco-lingual angular measurement in the xz-plane, Angle_xz_Left.

Midpoint_DMR_MMR_Left = the midpoint of the distal marginal ridge, DistalMarginalRidge_Left, and mesial marginal ridge, MesialMarginalRidge_Left, on the occlusal surface of the left mandibular third molar. This coordinates of this point were used to determine the displacement in three dimensions and calculate the total distance measured from the origin.

3.8 Defining Lines

Lines were used in this analysis to measure angles and can be defined by: selecting two points, or selecting two planes. For this investigation, lines were defined by selecting two landmarks, defined as points. Six lines were constructed, three per molar, using the previously identified and defined landmarks. Lines for both the right and left third molar were defined using setup function, under the "Reference" tab demonstrated in Figure 33 and 34.

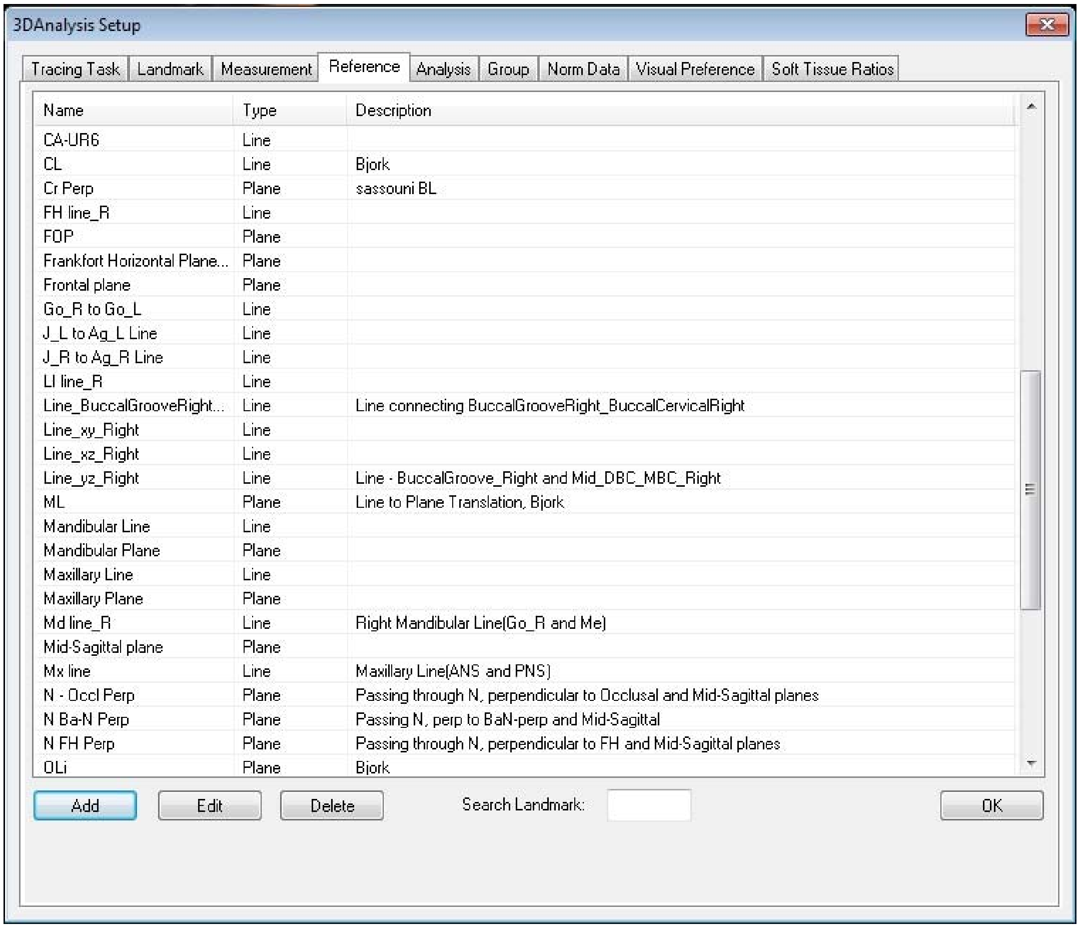


Figure 33. The Reference tab under the setup function demonstrates how lines and planes are defined.

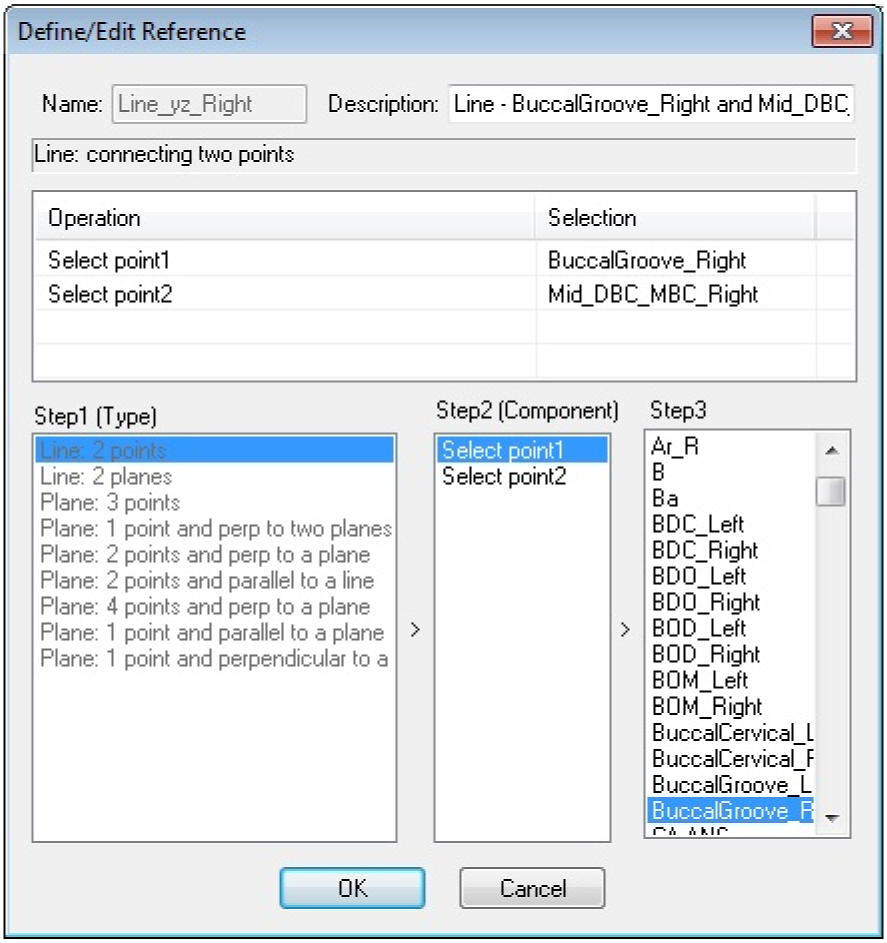


Figure 34. The line was defined by assigning a name, Line_yz_Right, which was composed of two points, Midpont_DBC_MBC_Left and BuccalGroove_Left. Line_yz_Right was used in order to measure the mesio-distal angular measurement in the yz-plane, Angle_yz_Right.

DEFINING RIGHT MOLAR LINES

Line_yz_Right = the line constructed from the two points: BuccalGroove_Right, the identified point, and the Midpoint_DBC_MBC_Right, the defined point. This line was used for angular measurements with the mandibular plane as seen in Figure 35.

Line_xz_Right = the line constructed from the two points: DistalMarginalRidge_Right, the identified point, and the Midpoint_LDC_BDC_Right, the defined point. This line was used for angular measurements with the mandibular plane as seen in Figure 36.

Line_xy_Right = the line constructed from DistalMarginalRidge_Right and MesialMarginalRidge_Right, both points that were identified. This line was used for angular measurements with the frontal plane as seen in Figure 37.

Figure 35. Line_yz_Right was constructed from the two points: BuccalGroove_Right, the identified point, and the Midpoint_DBC_MBC_Right, the defined point, used for angular measurements.

Figure 36. Line_xz_Right was constructed from the two points: BuccalGroove_Right, the identified point, and the Midpoint_DBC_MBC_Right, the defined point.

Figure 37. Line_xy_Right was constructed from DistalMarginalRidge_Right and MesialMarginalRidge_Right, both points that were identified. This line was used for angular measurements.

DEFINING LEFT MOLAR LINES

Line_yz_Left = the line constructed from the two points: BuccalGroove_Left, the identified point, and the Midpoint_DBC_MBC_Left, the defined point. This line was used for angular measurements with the mandibular plane.

Line_xz_Left = the line constructed from the two points: DistalMarginalRidge_Left, the identified point, and the Midpoint_LDC_BDC_Left, the defined point. This line was used for angular measurements with the mandibular plane.

Line_xy_Left = the line constructed from DistalMarginalRidge_Left and MesialMarginalRidge_Left, both points that were identified. This line was used for angular measurements with the frontal plane.

3.9 Linear Measurements

Measurements of linear displacement were calculated using the displacement formula between initial(i) and final(f) position in three planes of space. The displacement formulas used for this study:

$$\Delta x = x_f - x_i$$

$$\Delta y = y_f - y_i$$

$$\Delta z = z_f - z_i$$

RIGHT MOLAR

To determine the current position of the right third molar, the coordinates for the calculated landmark, Midpoint_DMR_MMR_Right, is obtained directly from the Landmark section of the 3D Analysis as shown in Figure 38. This method was used to obtain the current position with the corresponding coordinates of the left molar, determined by the point Midpoint_MMR_DMR_Right.

Figure 38. The origin for our analysis was designated at Midpoint_CLeft_Cright and the coordinates of the position of the tooth were obtained directly as the coordinates for Midpoint_MMR_DMR_Right = (31.2, 10.4, 5.9).

Right third molar position (x, 0, 0): position of right third molar measured at the Midpoint_DMR_MMR_Right to the Midpoint_CLeft_CRight, the origin, in the transverse direction.

Right third molar position (0, y, 0): position of right third molar measured at the Midpoint_DMR_MMR_Right to the Midpoint_CLeft_CRight, the origin, in the antero-posterior direction.

Right third molar position (0, 0, z): position of right third molar measured at the Midpoint_DMR_MMR_Right to the Midpoint_CLeft_CRight, the origin, in the inferior and superior direction.

The total distance of the third molars from the origin is calculated using the Euclidian distance formula:

$$\text{3D: } distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

In the example of the right third molar, the coordinates for tooth displacement, Midpoint_DMR_MMR_Right and Midpoint_CLeft_CRight, the origin was used to determine the total distance in three dimensions. The total distance was defined in the “Measurement” tab of the 3D analysis settings and the variable name TotalDistance_Right was assigned.

Right third molar distance (mm): the total amount of linear distance of Midpoint_DMR_MMR_Right to the Midpoint_CLeft_CRight, the origin, in three planes of space calculated using the Euclidian distance formula. Calculated by the defined line, TotalDistance_Right, and the distance was measured between the two points along the line in mm.

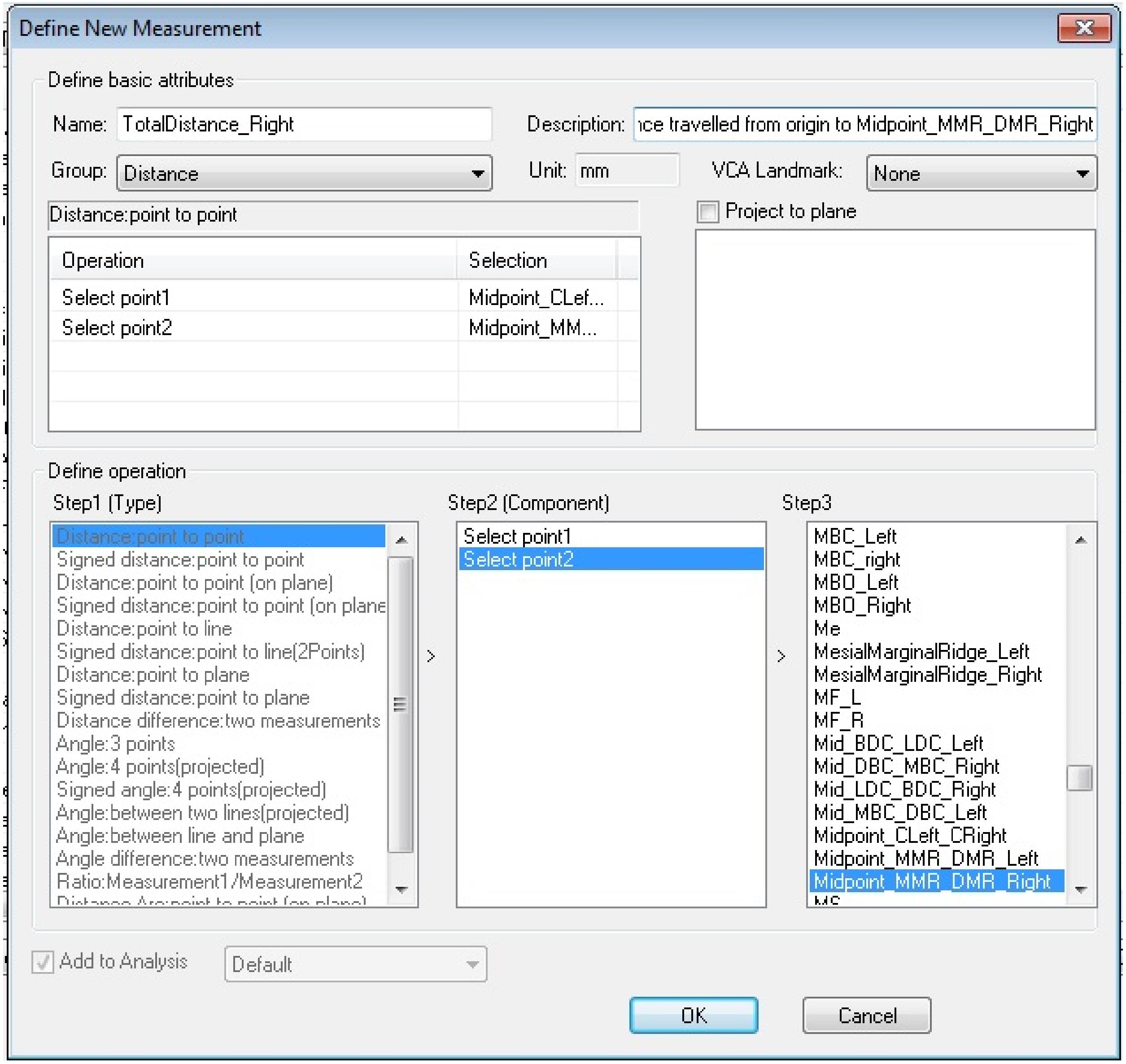


Figure 39. The total distance of the third molar measured from the origin was assigned the name TotalDistance_Right. The distance was calculated from the origin, Midpoint_CLeft_Cright, to the coordinates of the point, Midpoint_MMR_DMR_Right, in mm.

Figure 40. In this example, the total distance from the origin to the right third molar was calculated to be 33.44 mm using the Euclidean distance formula.

LEFT MOLAR

Left third molar position (x, 0, 0): position of left third molar measured at the Midpoint_DMR_MMR_Left to the Midpoint_CLeft_CRight, the origin, in the transverse direction

Left third molar position (0, y, 0): position of left third molar measured at the Midpoint_DMR_MMR_ Left to the Midpoint_CLeft_CRight, the origin, in the antero-posterior direction.

Left third molar position (0, 0, z): position of left third molar measured at the Midpoint_DMR_MMR_ Left to the Midpoint_CLeft_CRight, the origin, in the inferior and superior direction.

Left third molar distance (mm): the total amount of linear distance of Midpoint_DMR_MMR_Left to the Midpoint_CLeft_CRight, the origin, in three planes of space calculated using the Euclidian distance formula. Calculated by the defined line, TotalDistance_Left, and the distance was measured between the two points along the line in mm.

3.10 Angular Measurements

Angles were measured between a line and a plane, both were previously defined. To calculate the angle, the new measurement needs to be defined. Under the settings and measurement tab, a new measurement was added. An example of the Angle_yz_Right was defined in Figure 41.

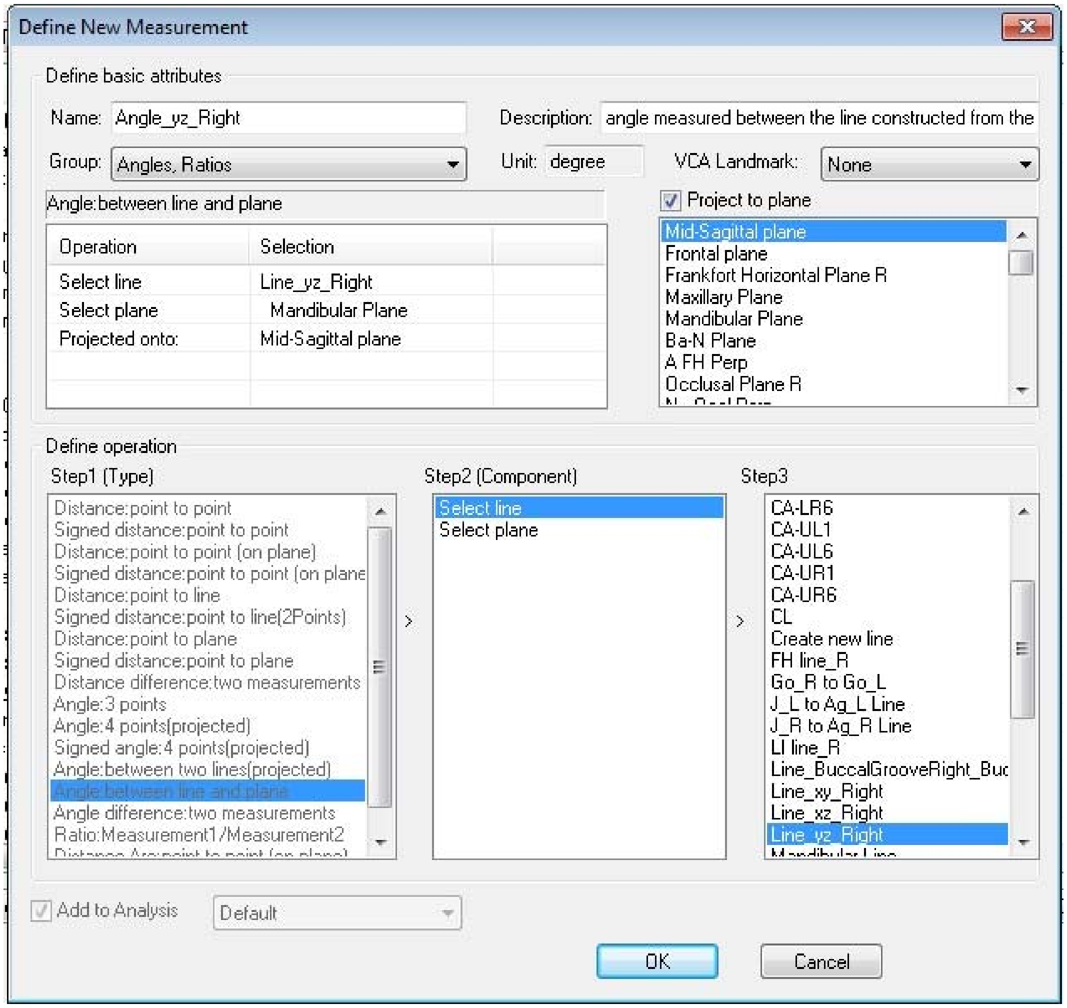


Figure 41. Angle_yz_Right was defined using Line_yz_Right and the Mandibular plane. The angle was projected onto the Mid-Sagittal plane easier visualization.

RIGHT MOLAR

Right third molar angulation (yz): angle measured between Line_yz_Right of the right mandibular third molar

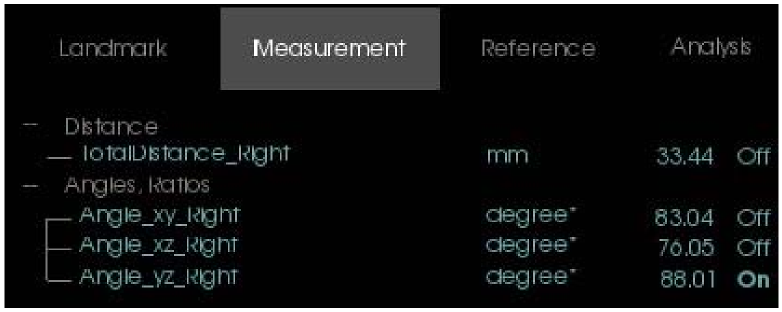


Figure 42. Angle_yz_Right is turned On in order to display the angle on the 3D image seen in Figure 43. Angle_yz_Right is measured to be 88.01 displayed on the analysis as well as in Figure 43.

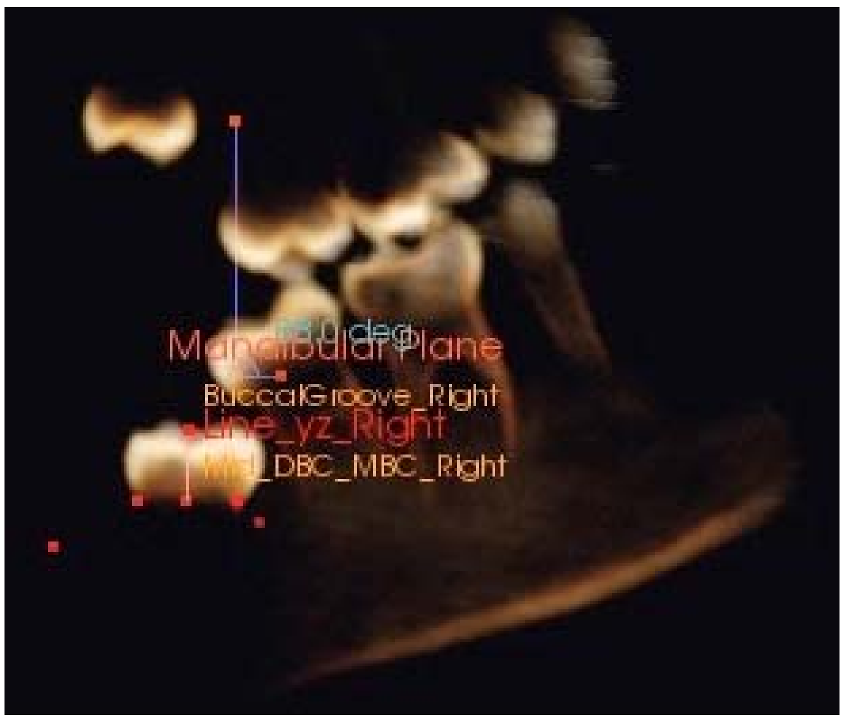


Figure 43. Angle_yz_Right can be seen formed from the angle created between Line_yz_Right and the mandibular axial plane. For visualization, Angle_yz_Right was projected onto the mid-sagittal plane.

Right third molar angulation (xz): angle measured between Line_xz_Right of the right mandibular third molar and the mandibular axial reference plane

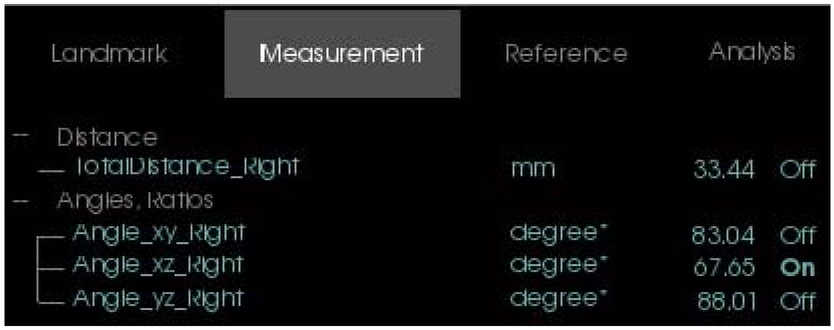


Figure 44. Angle_xz_Right is turned On in order to display the angle on the 3D image seen in Figure 45. Angle_xz_Right is measured to be 67.65 displayed on the analysis as well as in Figure 45.

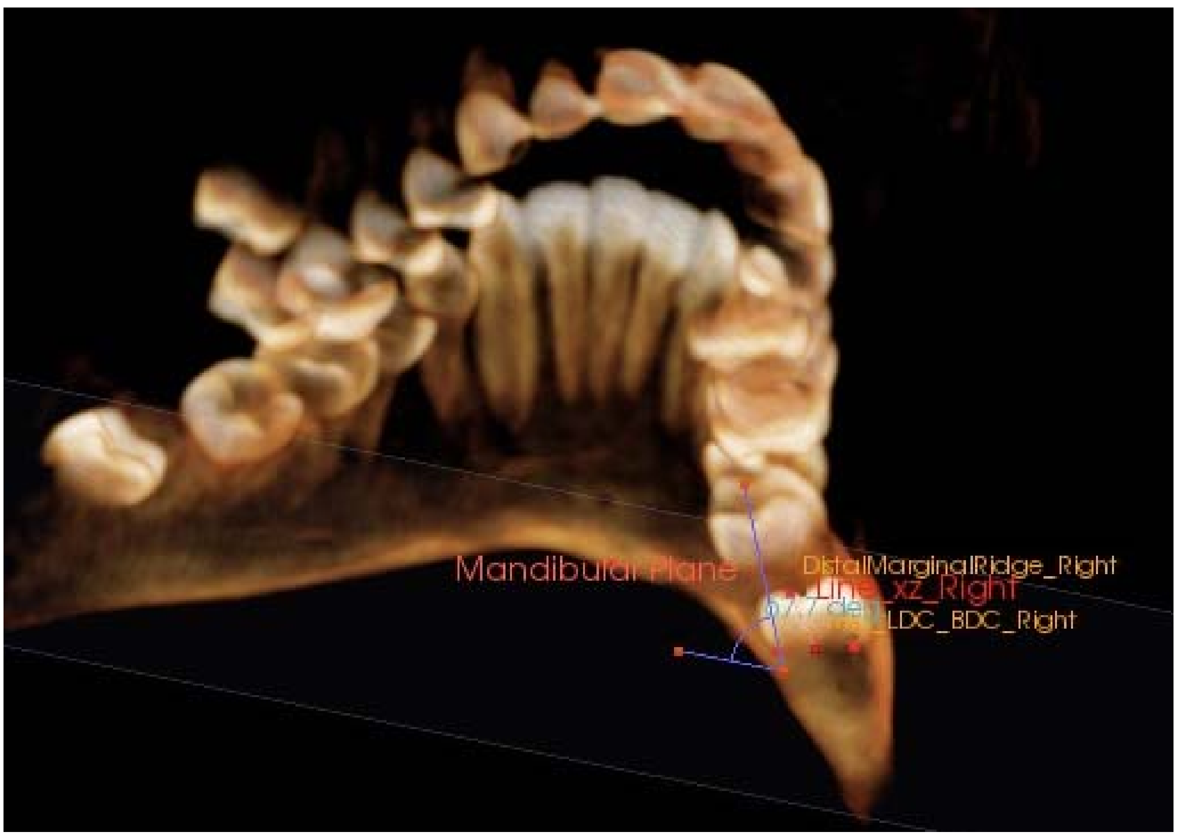


Figure 45. Angle_xz_Right can be seen formed from the angle created between Line_xz_Right and the mandibular axial plane. For visualization, Angle_xz_Right was projected onto the frontal plane.

Right third molar angulation (xy): angle measured between Line_xy_Right of the right mandibular third molar and the facial plane

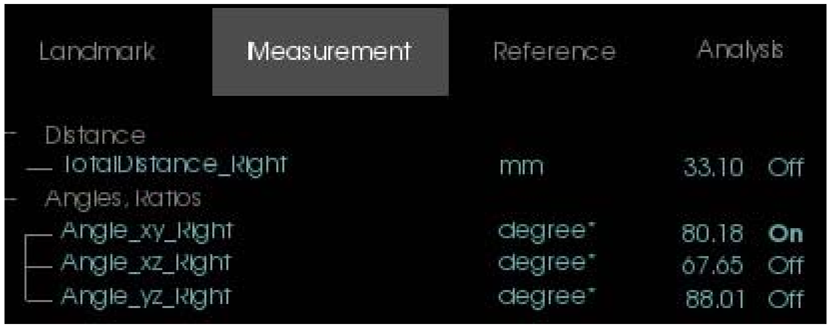


Figure 46. Angle_xy_Right is turned On in order to display the angle on the 3D image seen in Figure 47. Angle_xy_Right is measured to be 80.18 displayed on the analysis as well as in Figure 47.

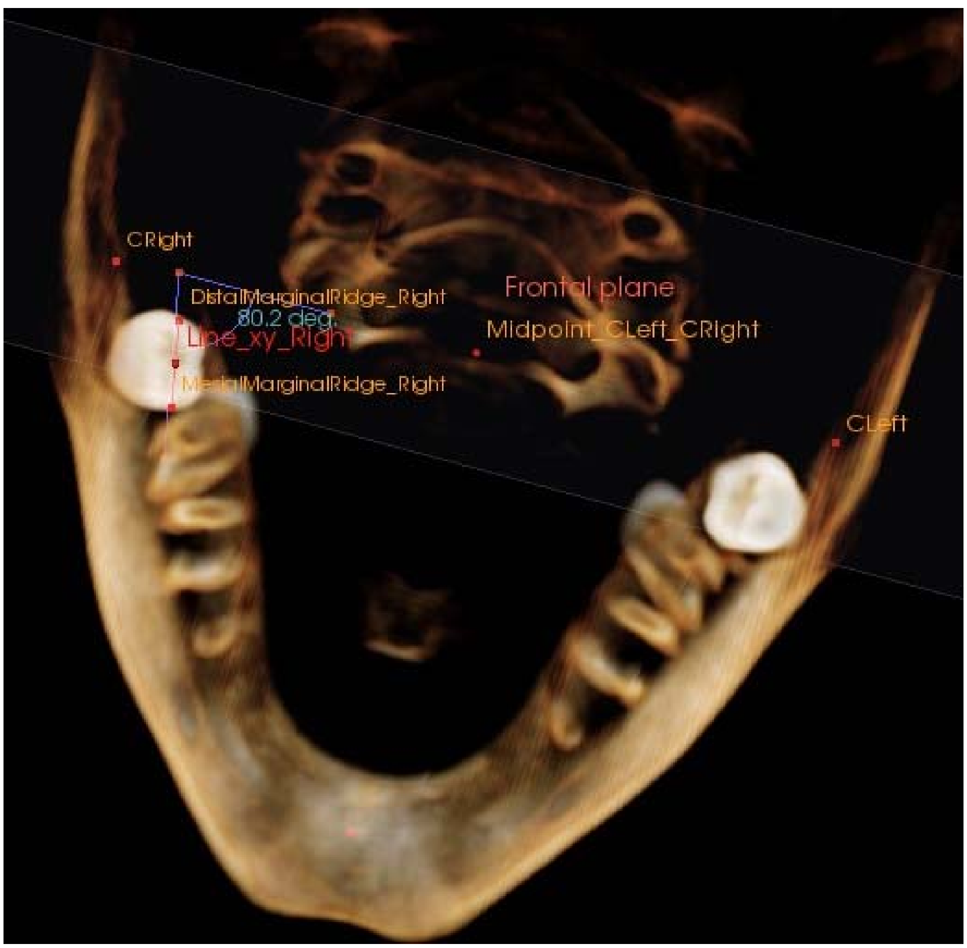


Figure 47. Angle_xy_Right can be seen formed from the angle created between Line_xy_Right and the frontal. For visualization, Angle_xy_Right was projected onto the mandibular plane.

LEFT MOLAR

Left third molar angulation (yz): angle measured between Line_yz_Left of the left mandibular third molar and the mandibular axial reference plane

Left third molar angulation (xz): angle measured between Line_xz_Left of the left mandibular third molar and the mandibular axial reference plane

Left third molar angulation (xy): angle measured between Line_xy_Left of the left mandibular third molar and the facial plane

3.11 Statistical Analysis

To evaluate intra-operator reliability of landmark identification and construction of reference planes, five CBCT images were randomly selected and reassessed a week later by the principal investigator. The landmarks were identified and the reference planes were constructed. Inter-operator reliability was examined by two different operators. Intra-class correlation coefficient was used to test the intra- and inter-operator reliability. The distribution of the raw data was investigated by Shapiro-Wilk test of normality.

For ease of data handling, each CBCT scan contains both a left and a right mandibular third molar allowing two third molars for analysis per subject. The measured variables was compared pre-treatment and post-treatment with the same third molar and within the same patient.

The pre-treatment and post-treatment means, standard deviations, and minimum and maximum values of the linear and angular changes in the x, y, and z planes were calculated for the mandibular third molars on the left and the right for each subject.

Paired t-tests was performed within each group after verifying that the data are normally distributed. An independent-samples 2-tailed t-test was used to perform the comparison between groups. Statistical analysis was performed using SPSS software version 22.0 (Armonk, NY: IBM Corp.). A significance level of 5% was chosen.

4. RESULTS

4.1 Data Analysis

Intra- and inter-class correlation coefficient (ICC) was used to assess intra and inter reliability of the method used. The intra and inter class correlation coefficients were higher than 0.85 with 95 % confidence interval ranging from 0.479 to 0.999, for the variables involved in this study indicating a good reliability of the method used in this study.

The majority of variables involving angular and positional measurements in the study were shown to be normally distributed according to the Shapiro-Wilk test of normality.

Paired t-tests were performed to test the mean difference between corresponding variables within a subject's left and right molar as well as pre-treatment to post-treatment within the experimental group and the control group of the variables involved in the study. Independent sample t-tests were performed to test the mean differences in variables between the experimental and control groups.

4.2 Class II Division 1

4.2.1 Comparison of Corresponding Pre-Treatment and Post-treatment Measurements within the Experimental Class II Division 1 Group

From the sample of subjects provided by the office personnel, 34 subjects met the inclusion criteria for the testing group and 35 for the control group. These subjects were divided based on diagnosis into two groups with an average age of 12.2415 for the treatment group and 12.0674 for the control group:

1. Class II Division 1 malocclusion (Experimental Group)
2. Class I malocclusion (Control Group)

TABLE I. GENDER DISTRIBUTION IN II EXPERIMENTAL AND I CONTROL GROUPS

		Gender		Total
		F	M	
Groups	Class II-Experimental	21	13	34
	Class I- Control	21	14	35
Total		42	27	69

TABLE II. AGE DISTRIBUTION IN EXPERIMENTAL AND CONTROL GROUPS

		Age (years)			
	N	Minimum	Maximum	Mean	Std. Deviation
Class II-Experimental	34	10.10	14.60	12.2415	1.16904
Class I- Control	35	9.06	17.08	12.0674	1.43178

The mean values of the measurements in this analysis were obtained from averaging the data for each corresponding variable for 34 subjects and are reported in Table I in the Appendix.

Paired sample t-tests were performed to assess the mean difference in corresponding angular and positional measurements between pre-treatment and post-treatment in cases that were Class II Division 1 malocclusion.

4.2.1.1 Positional Measurements

The results in Table III indicate that three of the variables in the study show statistically significant mean differences with p-values ranging from 0.001- to 0.003. The variables include Distance_x_Right, Distance_y_Right, Distance_y_Left. Based on this, the study rejects the null hypothesis that the no changes occur in mandibular third molar position in orthodontically treated patients with Class II Division 1 malocclusions pre-treatment to post-treatment.

4.2.1.2 Angular Measurements

The results in Table IV indicate that four of the variables in the study show statistically significant mean differences with p-values ranging from 0.001- to 0.003. The variables include Angle_yz,_Right, Angle_xz_Right, Angle_yz_Left, and Angle_xz_Left. Based on this, the study rejects the null hypothesis that the no changes occur in mandibular third molar angulation in orthodontically treated patients with Class II Division 1 malocclusions pre-treatment to post-treatment.

TABLE III. PAIRED T-TEST RESULTS FROM THE COMPARISON OF TOTAL POSITIONAL CHANGES IN PATIENTS WITH CLASS II DIVISION 1 MALOCCLUSIONS PRE-TREATMENT TO POST-TREATMENT

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
TotalDistanceRightPost - TotalDistanceRightPre	.1	1.2	.2	-.3	.5	.5	33	.7
TotalDistanceLeftPost - TotalDistanceLeftPre	.1	1.2	.2	-.3	.5	.6	33	.6
Distance_x_Right_Post - Distance_x_Right_Pre	-1.4	1.1	.2	-1.7	-1.0	-7.0	33	.0
Distance_y_Right_Post - Distance_y_Right_Pre	3.2	2.2	.4	2.4	4.0	8.4	33	.0
Distance_z_Right_Post - Distance_z_Right_Pre	.2	1.3	.2	-.2	.6	.9	33	.4
Distance_x_Left_Post - Distance_x_Left_Pre	.3	11.5	2.0	-3.7	4.3	.1	33	.9
Distance_y_Left_Post - Distance_y_Left_Pre	3.2	1.9	.3	2.5	3.8	9.9	33	.0
Distance_z_Left_Post - Distance_z_Left_Pre	-.2	1.2	.2	-.6	.2	-.8	33	.4

TABLE IV. PAIRED T-TEST RESULTS FROM THE COMPARISON OF ANGLULAR CHANGES IN PATIENTS WITH CLASS II DIVISION 1 MALOCCLUSIONS PRE-TREATMENT TO POST-TREATMENT

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Angle_yz_Right_Post - Angle_yz_Right_Pre	9.7	18.0	3.1	3.4	16.0	3.1	33	.0
Angle_xz_Right_Post - Angle_xz_Right_Pre	5.9	10.1	1.7	2.4	9.5	3.4	33	.0
Angle_xy_Right_Post - Angle_xy_Right_Pre	-1.0	5.2	.9	-2.8	.8	-1.1	33	.3
Angle_yz_Left_Post - Angle_yz_Left_Pre	8.3	8.9	1.5	5.2	11.4	5.4	33	.0
Angle_xz_Left_Post - Angle_xz_Left_Pre	8.9	13.0	2.2	4.3	13.4	4.0	33	.0
Angle_xy_Left_Post - Angle_xy_Left_Pre	-1.3	7.1	1.2	-3.8	1.1	-1.1	33	.3

4.2.2 Comparison of Corresponding Left and Right Measurements within the Experimental Class II Division 1 Group

The changes in pre-treatment and post-treatment measurements were determined by calculating the difference in post-treatment and pre-treatment measurements in the experimental group. Paired sample t-tests were then performed on these differences to assess the mean difference in corresponding angular and positional measurements within each subject's left third molar and right third molar in cases that were Class II Division 1 malocclusion.

4.2.2.1 Positional Measurements

The results indicate that no positional measurements show statistically significant mean differences. Based on this, the study fails to reject the null hypothesis that no differences were found in mandibular third molar position in orthodontically treated patients with Class II Division 1 malocclusion between the patient's right and left mandibular third molars.

TABLE V. PAIRED T-TEST RESULTS FROM THE COMPARISON OF POSITIONAL CHANGES IN PATIENTS WITH CLASS II DIVISION 1 MALOCCLUSIONS BETWEEN THE PATIENT'S RIGHT AND LEFT MANDIBULAR THIRD MOLAR

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
DifferenceTotalDistanceRight - DifferenceTotalDistanceLeft	.0	1.7	.3	-.6	.6	-.1	33	.9
Difference_Distance_x_Right - Difference_Distance_x_Left	-1.6	11.7	2.0	-5.7	2.4	-.8	33	.4
Difference_Distance_y_Right - Difference_Distance_y_Left	.0	1.3	.2	-.4	.5	.1	33	.9
Difference_Distance_z_Right - Difference_Distance_z_Left	.4	1.1	.2	.0	.7	1.9	33	.1

TABLE VI. PAIRED T-TEST RESULTS FROM THE COMPARISON OF ANGULAR CHANGES IN PATIENTS WITH CLASS II DIVISION 1 MALOCCLUSIONS BETWEEN THE PATIENT'S RIGHT AND LEFT MANDIBULAR THIRD MOLAR

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Difference_Angle_yz_Right - Difference_Angle_yz_Left	1.5	18.5	3.2	-5.0	7.9	.5	33	.6
Difference_Angle_xz_Right - Difference_Angle_xz_Left	-3.0	10.4	1.8	-6.6	.7	-1.6	33	.1
Difference_Angle_xy_Right - Difference_Angle_xy_Left	.4	9.1	1.6	-2.8	3.5	.2	33	.8

4.2.2.2 Angular Measurements

The results indicate that no angular measurements show statistically significant mean differences. Based on this, the study fails to reject the null hypothesis that no differences were found in mandibular third molar angulation in orthodontically treated patients with Class II Division 1 malocclusion between the patient's right and left mandibular third molars.

4.3 Class I

4.3.1 Comparison of Corresponding Pre-Treatment and Post-treatment Measurements within the Class 1 Control Group

The mean values of the measurements in this analysis were obtained from averaging the data for each corresponding variable for 35 subjects and are reported in Table II in the Appendix. Paired sample t-tests were performed to assess the mean difference in corresponding angular and positional measurements between pre-treatment and post-treatment in cases that were Class 1 malocclusion.

4.3.1.1 Positional Measurements

The results in Table VII indicate that five of the variables in the study show statistically significant mean differences with p-values ranging from 0.001- to 0.004. The variables include TotalDistanceLeft, Distance_x_Right, Distance_y_Right, Distance_x_Left, Distance_y_Left. Based on this, the study rejects the null hypothesis that no changes occur in mandibular third molar position in orthodontically treated patients with Class 1 malocclusions pre-treatment to post-treatment.

TABLE VII. PAIRED T-TEST RESULTS FROM THE COMPARISON OF POSITIONAL CHANGES IN PATIENTS WITH CLASS 1 MALOCCLUSIONS PRE-TREATMENT TO POST-TREATMENT

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
TotalDistanceRightPost - TotalDistanceRightPre	.2	1.5	.2	-.3	.7	.9	34	.4
TotalDistanceLeftPost - TotalDistanceLeftPre	-.5	1.4	.2	-1.0	-.1	-2.3	34	.0
Distance_x_Right_Post - Distance_x_Right_Pre	-.8	1.4	.2	-1.3	-.3	-3.1	34	.0
Distance_y_Right_Post - Distance_y_Right_Pre	1.7	2.4	.4	.9	2.5	4.1	34	.0
Distance_z_Right_Post - Distance_z_Right_Pre	.6	1.9	.3	-.1	1.2	1.7	34	.1
Distance_x_Left_Post - Distance_x_Left_Pre	-1.6	1.3	.2	-2.0	-1.1	-7.0	34	.0
Distance_y_Left_Post - Distance_y_Left_Pre	1.7	2.5	.4	.8	2.5	4.0	34	.0
Distance_z_Left_Post - Distance_z_Left_Pre	.6	1.8	.3	-.1	1.2	1.9	34	.1

4.3.1.2 Angular Measurements

The results in Table VIII indicate that there are no angular variables in the study showing statistically significant mean differences. Based on this, the study fails to reject the null hypothesis that no changes occur in mandibular third molar angulation in orthodontically treated patients with Class 1 malocclusions pre-treatment to post-treatment.

TABLE VIII. PAIRED T-TEST RESULTS FROM THE COMPARISON OF ANGULAR CHANGES IN PATIENTS WITH CLASS 1 MALOCCLUSIONS PRE-TREATMENT TO POST-TREATMENT

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Angle_yz_Right_Post - Angle_yz_Right_Pre	.9	7.0	1.2	-1.5	3.3	.8	34	.4
Angle_xz_Right_Post - Angle_xz_Right_Pre	.5	3.8	.6	-.8	1.8	.7	34	.5
Angle_xy_Right_Post - Angle_xy_Right_Pre	-.9	4.5	.8	-2.4	.7	-1.2	34	.3
Angle_yz_Left_Post - Angle_yz_Left_Pre	-1.3	8.9	1.5	-4.4	1.7	-.9	34	.4
Angle_xz_Left_Post - Angle_xz_Left_Pre	1.5	5.7	1.0	-.4	3.5	1.6	34	.1
Angle_xy_Left_Post - Angle_xy_Left_Pre	.7	6.1	1.0	-1.4	2.8	.7	34	.5

4.3.2 Comparison of Corresponding Left and Right Measurements within the Experimental Class I Control Group

Paired sample t-tests were performed to assess the mean difference in corresponding angular and positional measurements within each subject's left third molar and right third molar in cases that were Class I malocclusion.

4.3.2.1 Positional Measurements

The results in Table IX indicate two pairs with the mean difference of two of the variables in the study show statistically significant mean differences with p-value of 0.014. The pairs of variables include DifferenceTotalDistanceRight – DifferenceTotalDistanceLeft, Distance_x_Right_Post – Distance_x_Left_Post. Based on this, the study rejects the null hypothesis that no differences were found in mandibular third molar position in orthodontically treated patients with Class I malocclusion between the patient's right and left mandibular third molars.

4.3.2.2 Angular Measurements

The results in Table X indicate that there are no angular variables in the study showing statistically significant mean differences. Based on this, the study fails to reject the null hypothesis that no changes occur in mandibular third molar angulation in orthodontically treated patients with Class 1 malocclusions between the patient's right and left mandibular third molars.

TABLE IX. PAIRED T-TEST RESULTS FROM THE COMPARISON OF POSITIONAL CHANGES IN PATIENTS WITH CLASS 1 MALOCCLUSIONS BETWEEN THE PATIENT'S RIGHT AND LEFT MANDIBULAR THIRD MOLAR

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
DifferenceTotalDistanceRight - DifferenceTotalDistanceLeft	.8	1.9	.3	.1	1.4	2.3	34	.0
Difference_Distance_x_Right - Difference_Distance_x_Left	.8	1.8	.3	.2	1.4	2.7	34	.0
Difference_Distance_y_Right - Difference_Distance_y_Left	.0	1.7	.3	-.6	.6	.0	34	1.0
Difference_Distance_z_Right - Difference_Distance_z_Left	.0	1.5	.2	-.5	.5	.0	34	1.0

TABLE X. PAIRED T-TEST RESULTS FROM THE COMPARISON OF ANGULAR CHANGES IN PATIENTS WITH CLASS 1 MALOCCLUSIONS BETWEEN THE PATIENT'S RIGHT AND LEFT MANDIBULAR THIRD MOLAR

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Difference_Angle_yz_Right - Difference_Angle_yz_Left	2.2	11.5	1.9	-1.7	6.2	1.2	34	.3
Difference_Angle_xz_Right - Difference_Angle_xz_Left	-1.1	6.8	1.2	-3.4	1.3	-.9	34	.4
Difference_Angle_xy_Right - Difference_Angle_xy_Left	-1.6	6.6	1.1	-3.9	.7	-1.4	34	.2

4.4 Class II Division 1 Malocclusion vs Class I Malocclusion

4.4.1 Comparison of Corresponding Pre-treatment Measurements between the Class II Division 1 Experimental and Class 1 Control Group

The mean values of the measurements in this analysis were obtained from averaging the data for each corresponding variable for the 34 and 35 subjects in the experimental and control group respectively as seen in Table I and II in the appendix.

Independent sample t-tests were performed between the experimental and control group for each variable to assess the mean difference in corresponding pre-treatment angular and positional measurements between the Class II Division 1 and Class I group respectively.

4.4.1.1 Positional Measurements

The results in Table XI indicate that five of the positional variables in the study show statistically significant mean differences with p-values ranging from 0.001- to 0.037. The variables include TotalDistanceLeft, Distance_x_Right, Distance_y_Right, Distance_x_Left, Distance_y_Left. Based on this, the study rejects the null hypothesis that no differences are found in mandibular third molar position in orthodontically treated patients with Class II Division 1 malocclusion and Class I malocclusion.

4.4.1.2 Angular Measurements

The results in Table XII indicate that two of the angular variables in the study show statistically significant mean differences with p-values ranging from 0.001 to 0.034. The variables include Angle_yz_Right_Pre and Angle_yz_Left_Pre. Based on this, the study rejects the null hypothesis that no differences are found in mandibular third molar angulation in orthodontically treated patients with Class II Division 1 malocclusion and Class I malocclusion.

TABLE XI. RESULTS FROM THE DIFFERENCE IN THE POSITIONAL CHANGES PRE-TREATMENT AND POST-TREATMENT BETWEEN THE CLASS II DIVISION 1 MALOCCLUSION AND CLASS I MALOCCLUSION GROUPS

Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
DifferenceTotalDistanceRight	Class II - Experimental	34	.1	1.2	.2
	Class I - Control	35	.2	1.5	.2
DifferenceTotalDistanceLeft	Class II - Experimental	34	.1	1.2	.2
	Class I - Control	35	-.5	1.4	.2
Difference_Distance_x_Right	Class II - Experimental	34	-1.3	1.1	.2
	Class I - Control	35	-.8	1.4	.2
Difference_Distance_y_Right	Class II - Experimental	34	3.2	2.2	.4
	Class I - Control	35	1.7	2.4	.4
Difference_Distance_z_Right	Class II - Experimental	34	.2	1.3	.2
	Class I - Control	35	.6	1.9	.3
Difference_Distance_x_Left	Class II - Experimental	34	.3	11.5	2.0
	Class I - Control	35	-1.6	1.3	.2
Difference_Distance_y_Left	Class II - Experimental	34	3.2	1.9	.3
	Class I - Control	35	1.7	2.5	.4
Difference_Distance_z_Left	Class II - Experimental	34	-.2	1.2	.2
	Class I - Control	35	.6	1.8	.3

TABLE XII. INDEPENDENT SAMPLE T-TEST RESULTS FROM THE MEAN DIFFERENCE OF POSITIONAL CHANGES PRE-TREATMENT AND POST-TREATMENT BETWEEN THE CLASS II DIVISION 1 MALOCCLUSION AND CLASS I MALOCCLUSION GROUPS

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
DifferenceTotalDistanceRight	1.2	.3	-.4	67	.7	-.1	.3	-.8	.5
DifferenceTotalDistanceLeft	.1	.7	2.1	67	.0	.7	.3	.0	1.3
Difference_Distance_x_Right	.0	1.0	-1.9	67	.1	-.6	.3	-1.2	.0
Difference_Distance_y_Right	.0	.9	2.7	67	.0	1.5	.6	.4	2.6
Difference_Distance_z_Right	.3	.6	-.9	67	.4	-.4	.4	-1.1	.4
Difference_Distance_x_Left	2.5	.1	.9	67	.3	1.8	1.9	-2.0	5.7
Difference_Distance_y_Left	1.2	.3	2.8	67	.0	1.5	.5	.4	2.6
Difference_Distance_z_Left	1.7	.2	-2.0	67	.1	-.7	.4	-1.4	.0

TABLE XIII. RESULTS FROM THE DIFFERENCE IN THE ANGULAR CHANGES PRE-TREATMENT AND POST-TREATMENT BETWEEN THE CLASS II DIVISION 1 MALOCCLUSION AND CLASS I MALOCCLUSION GROUPS

Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Difference_Angle_yz_Right	Class II - Experimental	34	9.7	18.0	3.1
	Class I - Control	35	.9	7.0	1.2
Difference_Angle_xz_Right	Class II - Experimental	34	5.9	10.1	1.7
	Class I - Control	35	.5	3.8	.6
Difference_Angle_xy_Right	Class II - Experimental	34	-1.0	5.2	.9
	Class I - Control	35	-.9	4.5	.8
Difference_Angle_yz_Left	Class II - Experimental	34	8.3	8.9	1.5
	Class I - Control	35	-1.3	8.9	1.5
Difference_Angle_xz_Left	Class II - Experimental	34	8.9	13.0	2.2
	Class I - Control	35	1.5	5.7	1.0
Difference_Angle_xy_Left	Class II - Experimental	34	-1.3	7.1	1.2
	Class I - Control	35	.7	6.1	1.0

TABLE XIV. INDEPENDENT SAMPLE T-TEST RESULTS FROM THE MEAN DIFFERENCE OF POSITIONAL CHANGES PRE-TREATMENT AND POST-TREATMENT BETWEEN THE CLASS II DIVISION 1 MALOCCLUSION AND CLASS I MALOCCLUSION GROUPS

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Difference_Angle_yz_Right	4.1	.0	2.7	67	.0	8.8	3.3	2.3	15.3
			2.7	42	.0	8.8	3.3	2.1	15.5
Difference_Angle_xz_Right	9.7	.0	3.0	67	.0	5.5	1.8	1.8	9.1
			2.9	42	.0	5.5	1.9	1.7	9.2
Difference_Angle_xy_Right	.4	.5	-.1	67	.9	-.1	1.2	-2.4	2.2
			-.1	65	.9	-.1	1.2	-2.4	2.2
Difference_Angle_yz_Left	.5	.5	4.5	67	.0	9.6	2.1	5.3	13.9
			4.5	67	.0	9.6	2.1	5.3	13.9
Difference_Angle_xz_Left	6.1	.0	3.1	67	.0	7.4	2.4	2.5	12.2
			3.0	45	.0	7.4	2.4	2.5	12.3
Difference_Angle_xy_Left	.3	.6	-1.3	67	.2	-2.1	1.6	-5.3	1.1
			-1.3	65	.2	-2.1	1.6	-5.3	1.1

5. DISCUSSION

5.1 Choice of Methods

In this investigation, the angular and linear 3D tooth movements of developing third molars in orthodontically treated Class II Division 1 and Class I malocclusion patients were analyzed. The ability to study third molar angulation and position in three dimensions in this study for the purposes of exploring the treatment effects on developing third molars was made possible due to the availability of pre-treatment and post-treatment orthodontic records.

Conventional studies on the effects of third molars have been limited to 2D radiography and dental casts (Nalcaci et al., 2015). In the majority of previous studies measuring angulation, panoramic 2-D radiographs were used to determine the angular measurements and have been shown to be a reliable indicator in evaluating third molar mesoangulations (Olive and Basford, 1981; Larheim and Svannes, 1986). Cephalometric radiographs were not reliable due to the possible cause of errors in landmark identification due to the superimpositions of symmetric anatomic structures (Capelli, 1991; Erdem et al., 1998; Kim et al., 2003; Behbehani et al., 2006; Olive and Basford, 1981). Three dimensional evaluations were necessary in this investigation in order to be able to measure angulations and linear displacement in three planes of space. Limitations of 2D radiography include obtaining the measurement of mesial angulation only and no displacement due to distortions, and 2-D cepholmetric radiographs present with difficulties in landmark identification mentioned previously. While several studies performed 3-D tooth movement using pre-treatment and post-treatment dental casts, this was not possible in our investigation due to measurements being carried out on an unerupted developing third molar tooth buds.

In this investigation, 3-D measurements were performed on pre-treatment and post-treatment CBCT records. Therefore, it was necessary for the use of stable mandibular reference structures for reliable evaluation of changes as a result of orthodontic treatment. ICC reliability demonstrated that the methods employed for landmark identification proved to be reliable in this investigation. Therefore, the defined co-ordinate system and the establishment of the stable reference plane, adopted by a previous study (González et al., 2016), was suitable for the analysis.

5.2 Analysis and Clinical Implications of the Results

Third molar impaction is a difficult clinical problem that is challenging to predict at an early age. The fate of eruption predicted at an early age especially during the course of orthodontic treatment can reduce incidences of impactions. The subjects in this study ranged in age from 9 to 17 years, with a mean age of about 12 years old. This age group was chosen because the developing third molar bud is undergoing important rotational pre-eruptive movements during this time (Richardson, 1978; Silling, 1973). Optimal treatment timing for the Class II correction with the MARA appliance occurs at the pubertal growth spurt, determined to be around 11.4 years of age, to produce enhanced skeletal changes and minimal dentoalveolar compensations (Ghislanzoni et al., 2012). Patients were selected in this age group to determine whether the Class II treatment technique using mandibular advancement via functional appliance in conjunction with fixed appliance therapy vs. solely fixed appliance therapy to treat non-extraction patients had any favorable effect on the important pre-eruptive rotational and translational movements taking place during this stage of development.

In this investigation, an increased mesial angulation (Angle_yz) or buccal inclination (Angle_xz) represents a more upright third molar in its respective plane. Pre-treatment measurements for angulations were initially more upright for the Class I control group (Angle_yz_Right_Pre = 78.9 degrees, Angle_xz_Right_Pre = 49.7 degrees, Angle yz_Left_Pre = 79.7 degrees, Angle_xz_Left_Pre = 43.4 degrees) compared to the Class II experimental group (Angle_yz_Right_Pre = 70.9 degrees, Angle_xz_Right_Pre = 48.7 degrees, Angle yz_Left_Pre = 70.7 degrees, Angle_xz_Left_Pre = 44.0 degrees). Pre-treatment measurements for the Class II and Class I group can be found in Table I and II in the Appendix respectively. Regarding the positional pre-treatment measurements, the third molar position along the y-axis (Distance_y) for the control group (Distance_y_Right_pre = 15.4mm and Distance_y_Left_Pre = 15.7mm) was initially positioned more anteriorly compared to the experimental group (Distance_y_Right_pre = 13.3mm and Distance_y_Left_Pre = 13.8mm) which was more posteriorly positioned. This was expected and is explained by the skeletal discrepancy in the Class II Division 1 malocclusion experimental group that presented with mandibular retrognathism. This is important because approximately 4-6mm of molar correction is required to treat a Class II malocclusion. Therefore, anteroposterior third molar position along the y-axis for the experimental group was measured in a more posterior position pre-treatment compared to the Class I control group which was positioned more anteriorly.

5.2.1 Changes in Angulation

Following treatment in the experimental Class II group, a significant change in angulation was noted and was represented by an increase in third molar angulation leading to mesial and buccal molar uprighting. This was seen on both the left (Angle_yz_Left = 8.3 degrees, Angle_xz_Left = 8.9 degrees) and right (Angle_yz_Right = 9.7 degrees, Angle_xz_Right = 5.9 degrees). The treatment effects of the MARA in patients with Class II skeletal malocclusions included the mesial migration of lower molars (Pangrazio et al., 2012). Similar results reflecting an improvement in third molar mesial angulation as a result of mesial migration of the buccal segments has been reported in a previous study (Jain and Valiathan, 2009). Studies evaluating the buccal-lingual inclination of developing mandibular third molars have not yet been reported related to orthodontic therapy.

Third molar angulations in all dimensions changed minimally from pre-treatment to post-treatment for the Class I control group. The changes were not statistically significant. Hence, third molar angulations were maintained in each dimension and showed very minimal changes resulting from orthodontic treatment in the Class I malocclusion control group.

Comparing the angular changes between experimental and control groups, the difference in mesial angulations (Angle_yz_Right_Pre = 8.8 degrees and Angle_yz_Left_Pre = 9.6 degrees) and buccal angulations (Angle_xz_Right_Pre = 5.5 degrees and Angle_xz_Left_Pre = 7.4 degrees), were statistically significant between the groups. This corresponds to improved changes in mesial and buccal molar uprighting for the experimental group due to treatment when compared to the initial angulations in Table I and II in the Appendix.

5.2.2 Changes in Position

Significant changes in third molar position due to treatment for the Class II group involved displacement of the third molar anteriorly along the y-axis for both the left (Distance_y_Left = 3.2mm) and right (Distance_y_Right = 3.2mm) sides. This magnitude of mesial displacement is consistent with the study which reported a mesial migration of 3.23mm (Pangrazio et al., 2012). In the transverse dimension, significant displacement was noted for the left molar (Distance_x_Left = -1.4mm), a *negative* difference, representing a net medial movement along the x-axis towards the midline as a result of treatment. No significant positional changes were evident in the vertical z-axis, which was consistent with previous studies (Pangrazio et al., 2012). For the Class I control group, displacement of the third molar anteriorly along the y-axis was significant for both the left (Distance_y_Left = 1.7mm) and right (Distance_y_Right = 1.7mm) third molars. Since no treatment mechanics in the control group influenced anteroposterior correction, the displacement along the y-axis was likely attributed to other factors, such as growth. Along the x-axis in the transverse dimension, both displacement of the left (Distance_x_ Left = -1.6mm) and right (Distance_x_Right = -0.8mm) third molars resulted in a significant displacement. As discussed previously, a *negative* difference represented a net medial movement along the x-axis transversely towards the midline. Additionally, changes in total net displacement was significant in the control group for the left third molar (TotalDistanceLeftPost-TotalDistanceLeftPre = -0.5mm). Similar to the experimental group, no significant positional changes were evident along the vertical z-axis.

Comparing the positional changes between experimental and control groups, the change in total displacement of the left third molar (DifferenceTotalDistanceLeft = 0.7mm) and displacement along the y-axis for the right (Difference_Distance_y_Right = 1.5mm) and left (Difference_Distance_y_Left = 1.5mm) third molars were statistically significant. The results for anteroposterior displacement compared between experimental and control group corroborate those discussed previously since the net 3mm change in displacement along the y-axis in the experimental group contributes to 1.7mm of the anterior displacement due to factors other than treatment such as growth and the other 1.5mm due to the mesial migration of the molars. The total distance in the left molar only (DifferenceTotalDistanceLeft = 0.66mm) was statistically significant when comparing experimental and control group.

5.2.3 Measurements of Left vs Right

There were no statistically significant third molar angulation measurements in both the experimental and control group comparing corresponding changes pre-treatment to post-treatment within subjects between left and right third molars. Hence, corresponding third molar angulations in all dimensions were similar in all cases comparing between left and right within the experimental and control group.

However, our findings for the positional measurements of third molars comparing corresponding measurements on the left and right within the control group were statistically significant for the total distance (DifferenceTotalDistanceRight-DifferenceTotalDistanceLeft = 0.75mm) and the displacement along the x-axis (Difference_Distance_x_Right - Difference_Distance_x_Left =0.8mm).

5.3 Limitations

There were a few noteworthy limitations to the present study. Landmark identification was crucial to the tracing task in order to ensure accurate reliable measurements for the analysis. While the ICC analysis determined the methodology was reliable, many potential subjects were excluded due to the inability to clearly identify landmarks due to the wide variation landmarks of developing third molars. Secondly, the use of an untreated Class II control group to compare the effects of treatment to the experimental group to correct the Class II will provide a more accurate comparison of the precise effects of treatment on the third molars. Additionally, it is important to know whether the changes in angulation and position provided clinically relevant result which decreases chances of impactions in the future, therefore a post-retention follow up to determine long term outcomes will provide more relevant information on impactions. Finally, this appliance explores treatment effects to correct the Class II using only one of many types of fixed appliances. Other Class II appliances have different mechanics and treatment effects (headgear, Herbst, class II elastics) and therefore may have different results due to Class II correction.

5.4 Strengths

This present study was the first to explore the treatment effects of appliance therapy on third molar angulations and position in three dimensions for Class II Division 1 malocclusions in addition to Class I malocclusions. The availability of pre-treatment and post-treatment 3D CBCT records made it possible to conduct the study due to the sufficiently large enough sample size with identical control group in terms of total number of subjects and gender distribution. The study also focused on the treatment timing and effects which validated those in previous studies and has contributed to the effects treatment with the MARA has on the third molar angulation and position.

5.5 Future Studies

Replicating the study with an untreated Class II control group will strengthen the current study. Additionally, a post-retention follow up to determine if the changes had any relapse. Long term follow up of same patients to determine if the orthodontic effects on third molars provided with clinically significant predictive information on impaction. Extension of the current study to include maxillary third molars to determine 3-D treatment effects on maxillary third molars as a result of treatment can provide insight into the behavior of maxillary third molars.

5.6 Clinical Significance

Class II correction with mandibular dentoalveolar advancement improves mesial and buccal uprighting of the third molar. This information will assist in treatment decisions on third molar impaction in the future if correlations can be made with the results of this study as a predictive determinant for impaction. This investigation also provides insight on the 3-D behavior of third molars due to orthodontic treatment when fixed appliances only with no anteroposterior correction are in place vs. functional appliance in conjunction with fixed appliances.

6. CONCLUSIONS

The present findings showed that Class II correction with non-extraction mandibular advancement appliance therapy results in favorable rotational and positional changes in the mandibular third molar. Mesial angulation and buccal inclination of third molars improved as a result of Class II correction with the MARA appliance in conjunction with fixed appliance therapy. Change in position was evident for both Class II and the Class I group in the anteroposterior and transverse dimensions. There was greater change for the Class II group anteriorly resulting from mesial migration of molars due to treatment. In the transverse dimension, positional changes due to treatment occurred medially for both groups. There was no significant difference between angulation in both groups within subjects left and right third molars. However, a significant difference in positional change was found for total distance and transverse position within the left and right third molars in the Class I group.

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APPENDIX

Notice of Determination of Human Subject Research

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Notice of Determination of Human Subject Research

October 26, 2016

20161071-100622-1

Rory Chong, DDS
Orthodontics
801 S. Paulina Street, RM 131
Chicago, IL 60612
Phone: (312) 996-7505 / Fax: (312) 996-0873

RE: **Protocol # 2016-1071**
Mandibular Third Molar Position and Angulation in Orthodontically Treated Patients with Class II Malocclusion

Sponsor(s): None

Dear Dr. Chong:

The UIC Office for the Protection of Research Subjects received your "Determination of Whether an Activity Represents Human Subjects Research" application, and has determined that this activity **DOES NOT meet the definition of human subject research** as defined by 45 CFR 46.102(f).

To conduct the study, initial and final records will be assessed of 200 subjects, 100 each, by office personnel with either Class II Division 1 malocclusion or Class I malocclusion who were treated at Jacobson and Tsou Orthodontics, a private practice located in Chicago, Illinois. The CBCT images will be de-identified by the office personnel, and de-identified descriptive information and diagnostic treatment summaries void of any HIPAA identifiers will be provided to the principal investigator. The descriptive information including: age at beginning of treatment, diagnosis, ANB, overjet, % Class II on the left, % Class II on the right, length of treatment, bracket slot size, type of treatment and appliances used. The diagnostic treatment summaries includes: problem list, mechanics, and treatment sequence.

Because the research will not involve human subjects at UIC, you may conduct your activity without further submission to the IRB. Please note, however, that HIPAA requirements must be addressed by Jacobson and Tsou Orthodontics staff since they will be using (but not disclosing) Protected Health Information for this research purpose.

If this activity is used in conjunction with any other research involving human subjects or if it is modified in any way, it must be re-reviewed by OPRS staff.

cc: Carla Evans, Orthodontics, M/C 841

STUDY CERTIFICATION

August 23, 2016

University of Illinois at Chicago
Office for the Protection of Research Subjects (OPRS)
1737 West Polk Street (MC672)
203 Administrative Office Building
Chicago, IL 60612

Dear Institutional Review Board,

This letter grants permission to Dr. Rory Chong to use cone beam computed tomography (CBCT) scans and related information including the dates of the scans from my orthodontic practices in Chicago, Illinois for the purpose of obtaining measurements for use in analysis of third molar angulation and position obtained from CBCT scans among healthy young individuals.

I have reviewed the research protocol and I understand that this research will be conducted using archived patient CBCT scans and will have minimal risk to my patients. In order to protect the confidentiality of my patients and to abide by the HIPAA regulations, each patient will be assigned a number (for example 1,2,3). All of the patients' protected health information (PHI) will be removed from the files provided to Dr. Rory Chong. The key that associates the specific codes and PHI will be kept as part of my database but will not be provided to Dr. Rory Chong.

I understand that the digital files thus provided will suffice to support Dr. Rory Chong in his research according to his research protocol.

Please do not hesitate to contact me if you have any questions or concerns.

Sincerely,

R Jacobson

Ronald S. Jacobson, D.D.S., M.S.

Tables

Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Angle_yz_Right_Pre	Class II - Experimental	34	70.8685	17.66618	3.02973
	Class I - Control	35	78.8957	9.89156	1.67198
Angle_xz_Right_Pre	Class II - Experimental	34	48.6635	14.40536	2.47050
	Class I - Control	35	49.6600	13.60177	2.29912
Angle_xy_Right_Pre	Class II - Experimental	34	77.6953	10.16371	1.74306
	Class I - Control	35	77.7157	9.11692	1.54104
Angle_yz_Left_Pre	Class II - Experimental	34	70.7791	10.07603	1.72802
	Class I - Control	35	79.6926	8.93010	1.50946
Angle_xz_Left_Pre	Class II - Experimental	34	43.9979	17.49220	2.99989
	Class I - Control	35	43.3954	14.32956	2.42214
Angle_xy_Left_Pre	Class II - Experimental	34	78.7247	9.87994	1.69440
	Class I - Control	35	78.4109	7.33718	1.24021
Angle_yz_Right_Post	Class II - Experimental	34	80.5938	10.83442	1.85809
	Class I - Control	35	79.8106	10.03300	1.69589
Angle_xz_Right_Post	Class II - Experimental	34	54.5897	11.87993	2.03739
	Class I - Control	35	50.1311	12.63856	2.13631
Angle_xy_Right_Post	Class II - Experimental	34	76.7118	9.15347	1.56981
	Class I - Control	35	76.8403	8.72608	1.47498
Angle_yz_Left_Post	Class II - Experimental	34	79.0379	8.55883	1.46783
	Class I - Control	35	78.3717	8.68386	1.46784
Angle_xz_Left_Post	Class II - Experimental	34	52.8765	15.84560	2.71750
	Class I - Control	35	44.9180	14.61289	2.47003
Angle_xy_Left_Post	Class II - Experimental	34	77.3753	12.45658	2.13629
	Class I - Control	35	79.1260	6.43067	1.08698

Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
TotalDistanceRightPre	Class II - Experimental	34	35.3029	1.43624	.24631
	Class I - Control	35	36.0234	1.37797	.23292
TotalDistanceLeftPre	Class II - Experimental	34	35.3406	1.21730	.20877
	Class I - Control	35	36.1251	1.39409	.23564
Distance_x_Right_Pre	Class II - Experimental	34	32.1324	1.52370	.26131
	Class I - Control	35	32.1089	1.61162	.27241
Distance_y_Right_Pre	Class II - Experimental	34	13.3265	3.26332	.55966
	Class I - Control	35	15.3886	2.75401	.46551
Distance_z_Right_Pre	Class II - Experimental	34	4.0971	1.48538	.25474
	Class I - Control	35	3.3571	1.63406	.27621
Distance_x_Left_Pre	Class II - Experimental	34	30.3559	11.09073	1.90205
	Class I - Control	35	31.9829	1.50987	.25521
Distance_y_Left_Pre	Class II - Experimental	34	13.8476	2.87994	.49391
	Class I - Control	35	15.7200	2.66080	.44976
Distance_z_Left_Pre	Class II - Experimental	34	4.4353	1.18139	.20261
	Class I - Control	35	3.0086	1.83806	.31069
TotalDistanceRightPost	Class II - Experimental	34	35.3971	1.77082	.30369
	Class I - Control	35	36.2334	1.94432	.32865
TotalDistanceLeftPost	Class II - Experimental	34	35.4600	1.48408	.25452
	Class I - Control	35	35.5837	1.90443	.32191
Distance_x_Right_Post	Class II - Experimental	34	30.7824	1.49006	.25554
	Class I - Control	35	31.3429	2.13601	.36105
Distance_y_Right_Post	Class II - Experimental	34	16.5176	3.39924	.58296
	Class I - Control	35	17.0786	3.19658	.54032
Distance_z_Right_Post	Class II - Experimental	34	4.2941	1.61413	.27682
	Class I - Control	35	3.9143	2.33945	.39544
Distance_x_Left_Post	Class II - Experimental	34	30.6353	1.40214	.24046
	Class I - Control	35	30.4171	1.77391	.29985
Distance_y_Left_Post	Class II - Experimental	34	17.0235	3.06209	.52514
	Class I - Control	35	17.3974	3.60681	.60966
Distance_z_Left_Post	Class II - Experimental	34	4.2706	1.69071	.28995
	Class I - Control	35	3.5657	2.28021	.38543

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