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# Differential CBCT Analysis of Collum Angles in Maxillary and Mandibular Anterior Teeth in Patients with Different Malocclusions

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DIFFERENTIAL CBCT ANALYSIS OF COLLUM ANGLES IN MAXILLARY AND MANDIBULAR ANTERIOR TEETH IN PATIENTS WITH DIFFERENT MALOCCLUSIONS

By

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Abstract

**Background:** The collum angle is an angular measurement of the difference between the longitudinal axis of the crown and the longitudinal axis of the root. The aim of this study was to determine the mean collum angles for all maxillary and mandibular anterior teeth. In addition, the collum angles of different molar and skeletal classifications were compared for each anterior tooth.

**Methods:** Based on patient records obtained from the University of Nevada, Las Vegas Department of Orthodontics and Dentofacial Orthopedics, 326 CBCT scans were selected and divided into four molar and skeletal classifications. The patients were divided into Class I, Class II division 1, Class II division 2, and Class III molar and skeletal classifications. For the molar classifications, each side of a patient's mouth was considered a different sample, whereas in the skeletal classifications, both sides were classified in the same way. After the exclusion criteria, the total sample size used in this study was 652. The collum angles of all anterior teeth were then measured using the angular measurement tool built into Invivo 5.4.5's software.

**Results:** The mean collum angles for the maxillary central incisors, lateral incisors and canines were 4.13± 6.17 degrees, 6.20±6.53 degrees and 1.11± 6.82 degrees, respectively. For the mandibular arch, the mean collum angle for the central incisors was 5.94±3.71 degrees. The mean collum angles for the mandibular lateral incisors and canines were 6.49±4.32 degrees and 7.82±4.73 degrees. A one sample t-test indicated that all of the collum angles in the anterior teeth were significantly different from zero. An analysis of variance (ANOVA) in conjunction with a Bonferonni post-hoc test was

conducted between the molar and skeletal classifications. In the comparison with molar classifications, the maxillary central and lateral incisors were significantly different in the Class II div 2 malocclusion when compared to all other molar classifications. The Class II div 2 collum angle for the maxillary central incisor was 7.86±6.10 degrees, whereas the collum angle for the maxillary lateral incisor was 2.47±6.14 degrees. A similar result was seen in the comparison with skeletal classifications. The Class II div 2 maxillary central incisor had a mean collum angle of 8.91±5.98 degrees whereas the maxillary lateral had a mean collum angle of 1.82±7.15 degrees. A mean comparison between the skeletal and molar classifications indicated that the mean collum angles were not significantly different between the different types of classifications.

**Conclusions:** The mean collum angles found in anterior teeth were significantly different from zero. When comparing these collum angles between different molar malocclusions, the Class II div 2 maxillary central incisors had significantly larger collum angles, while the maxillary lateral incisors had significantly smaller collum angles. The larger collum angle found in Class II div 2 maxillary centrals may possibly be an etiological factor in the development of a deep bite. In addition, larger collum angles may limit biomechanical movements during orthodontic treatment. In particular, attention must be given to root proximity to the cortical plate. Extrusive, intrusive and torquing forces must be carefully examined in teeth with large collum angles in order to prevent root resorption, dehiscences and alveolar perforation during fixed appliance therapy.

## Acknowledgements

First and foremost, I would like to thank my research committee, Dr. James Mah, Dr. Stanley Nelson, Dr. Ronald Lemon, Dr. Edward Herschaft, Dr. Tanya Al-Talib, and Dr. Debra Martin for their continued support throughout this project. Their guidance and expertise allowed me to further my knowledge in the both the topic being studied and in the field of dentistry. In particular, I would like to thank my committee as a whole for revising my thesis and providing the constructive criticism required to complete my project. Without their input and constant support, the completion of this thesis would not have been possible.

Secondly, I would like to thank Dr. Paul Brown for his continued enthusiasm and interest in this subject. His constant motivation gave me the stamina to overcome the challenges encountered during the completion of this project. His unwavering optimism and genuine passion for this topic has been an invaluable source of support and I cannot be more grateful to have had such a mentor.

Thirdly, I would like to thank Dr. Marcia Ditmyer for her assistance in statistically analyzing the data. Without her guidance, the statistical analysis would not have been possible. By pursuing the statistical analysis of the project together, I was able to greatly expand my knowledge in the field of statistics.

Furthermore, I would like to thank my research assistants, Luzanne Ermita and Irina Sharp for their assistance in anonymizing CBCT scans and categorizing the data. By helping me lay the groundwork for this project, they made this project possible in the time frame available.

Last but not least, I would like to thank my friends and family for their support in the preparation of this thesis. Special thanks to Michael Weintraub and Jordan Shiraki for their work in Illustrator and Photoshop. Without their help, the diagrams would have been much less spectacular. Finally, I would like to thank Andrew Shaffer for his unconditional support and technical expertise. Although his assistance in data evaluation allowed for the timely continuation of this study, it was his continued encouragement and devotion that gave me the inspiration to complete this project.

Dedication

To my parents,

Who have supported me unconditionally throughout my academic career.
I am eternally grateful for your patience, generosity, and everlasting love.

To Andrew Shaffer,
Who has been my foundation throughout residency.
I cannot even begin to express my gratitude for your unwavering support and ceaseless encouragement.
Thank you for all you have done.

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# Chapter 1: Introduction

Variability in tooth anatomy inherently affects occlusion and its corresponding three dimensional positions (Bryant, 1984). Anatomically, the shape of a lateral incisor can affect esthetics and general intercuspation, whereas, the lingual shape of a central incisor can affect its interarch relationships and bite depth. In relation to orthodontics and bracket positioning, the variability in labial crown curvature affects the slot of a bracket and its relationship to the occlusal plane (Bryant, 1984). Likewise, the axial inclination of a tooth is a key variant in anatomical morphology. When looking at axial inclination, one is typically inclined to evaluate only the crown, assuming that the root follows the same axis. On inspection of most anterior teeth, it can be noted that the longitudinal axis of the crown of a tooth can vary significantly from the longitudinal axis of the root. The corresponding angle between these two longitudinal axes is defined as the crown to root angle. The collum angle, therefore, is the supplementary angle of the crown to root angulation, used to correlate the angular difference between the two axes.

Although the collum angle has been described in literature, it is generally assumed the difference between the axes is zero degrees (Bauer, 2014). In particular, this assumption has been ingrained in the use of cephalometric templates (Bryant, 1984). For example, Bjork defines the longitudinal axis of a central incisor as a line passing through the incisor superiorus to the apex of a tooth (Bjork, 1947). This longitudinal axis is then compared to other cephalometric reference lines as a quantification of incisor inclination.

The aforementioned assumption is erroneous, as the longitudinal axis does not account for the morphological bending of the crown in relation to the root.

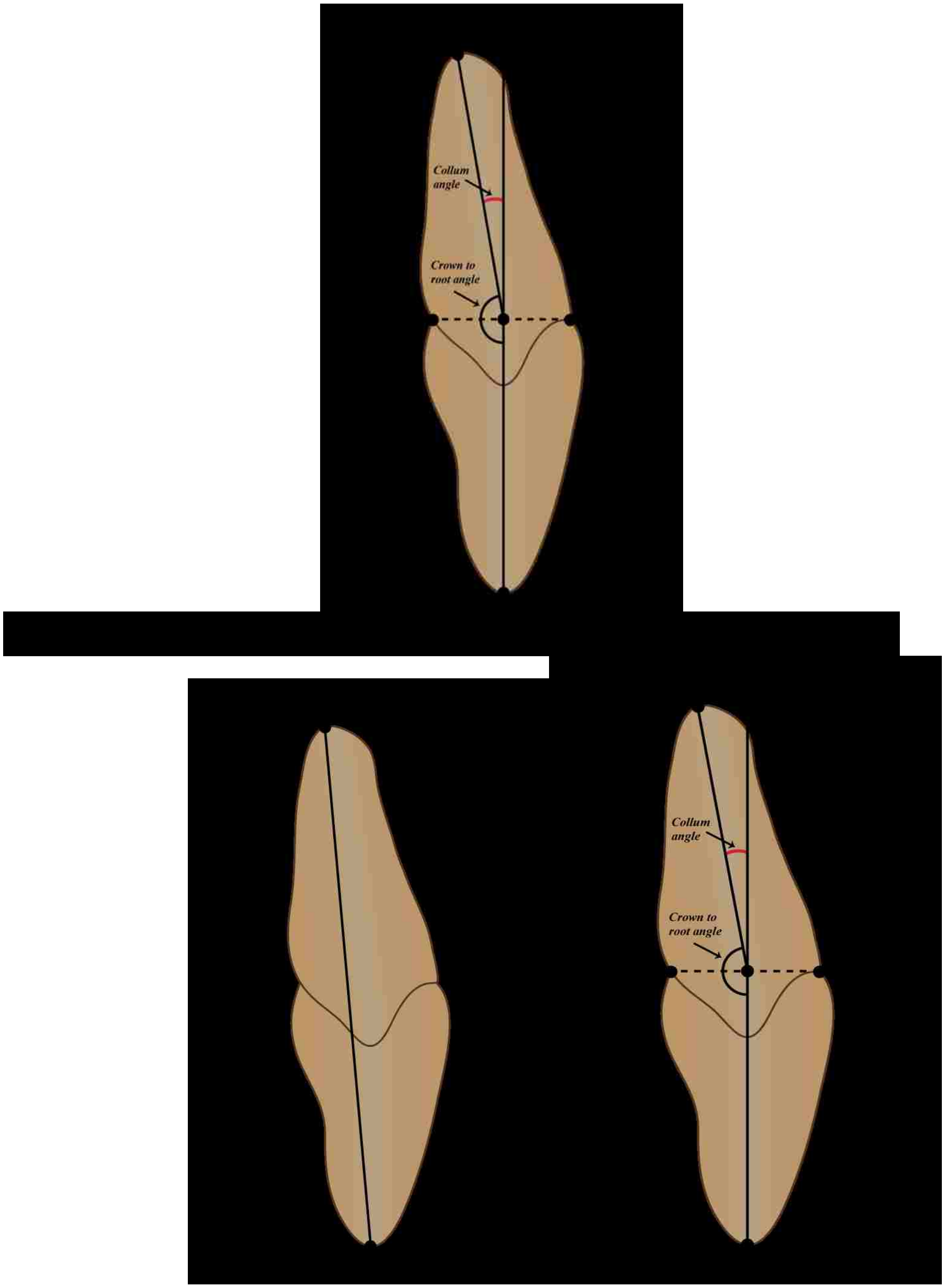


*Figure 1.2. Bjork's definition of the longitudinal axis of a tooth. It can be seen that this definition disregards the different axes between the crown and the root.*

This assumption may have also transcended into the development of the Straight Wire Appliance. The Straight Wire Appliance as designed by Dr. Lawrence Andrews is currently used as the staple appliance in orthodontics. It was designed with built in bracket prescriptions to prevent the laborious task of extensive wire bending in finishing orthodontic cases. The appliance, however, may have incorporated the previous assumption that the angle between the crown and root axes for every tooth is zero degrees. The lack of consideration for the crown to root angle is therefore, a limitation in the straight wire appliance, as it does not account for the variability of root position in relation to the crown. This is especially important in the esthetic segment where torquing of the crowns may affect root position. In severe cases, the root may inadvertently encroach the labial or lingual cortical plates, causing unwarranted root resorption and dehiscences (Harris, 1993). In addition, aberrant crown to root angulations may confound intended axial loading when attempting to intrude or extrude teeth (Harris, 1993). Thus, the angle created by the anatomical axes of the crown and root may have a significant impact in the treatment of orthodontics.

In this study, the crown to root angle of the anterior teeth will be measured and correlated to different types of malocclusions classified in orthodontics. As the supplementary angle of the crown to root angulation, the collum angle is used to more comprehensively demonstrate the amount of labio-lingual angulation of the crown to the root. Specifically, the collum angle will be used to quantify the crown to root angle measurements in this study.

The collum angle for a maxillary central incisor has been measured and compared in different malocclusions. However, these studies have been done with lateral cephalometric x-rays where differentiation of anatomic structures may be difficult. Because of the nature of a lateral cephalometric x-ray, where superimposition of structures is a problem, there has yet to be an analysis of the lateral incisors and canines with regards to molar malocclusions. These lateral incisors and canines are of similar importance to the central incisors since they are part of the esthetic segment. In addition, the quantification of the collum angles in the mandibular arch has not been conducted. This may be particularly useful as the interdigitation of the maxillary arch depends on the incisal inclination of the mandibular arch. The aim of this study, therefore, is to more accurately quantify the relationship of the collum angle to different molar classifications and to determine the previously unmeasured collum angles of all anterior teeth in each arch. With this groundwork laid out, further investigation will be conducted to see if there are any changes in collum angles between each anterior tooth in differing skeletal classifications.

The intent of this study is to:

1. Determine the mean collum angle for each anterior tooth
2. Determine if the mean collum angles are significantly different from zero
3. Test for significant differences in the collum angles of maxillary and mandibular anterior teeth with different molar malocclusions

4. Test for significant differences in the collum angles of maxillary and mandibular anterior teeth with different skeletal malocclusions

**Research Questions and Hypotheses**

1. What is the mean collum angle for each type of anterior tooth?

2. Is there a difference in collum angle measurements from the expected angle of zero degrees?

3. Is there a significant difference (p=0.05) between the collum angles of Class I, Class II div 1, Class II div 2, and Class III molar malocclusions of the maxillary central incisors, maxillary lateral incisors and maxillary canines in a sample of orthodontic patients at the UNLV SDM clinic?

   Null Hypothesis: There is no significant difference between the Class I, Class II div 1, Class II div 2, and Class III molar malocclusions in the maxillary central incisor, maxillary lateral incisor and maxillary canine collum angles in a sample of orthodontic patients in the SDM clinic.

   Alternative Hypothesis: There is a significant difference between the Class I, Class II div 1, Class II div 2, and Class III molar malocclusions in the maxillary central incisor, maxillary lateral incisor and maxillary canine collum angles in a sample of orthodontic patients in the SDM clinic.

4. Is there a significant difference (p=0.05) between Class I, Class II div 1, Class II div 2, and Class III molar malocclusions in the mandibular central incisor,

mandibular lateral incisor, and the mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic?

Null Hypothesis: There is no significant difference between the Class I, Class II div 1, Class II div 2, and Class III molar malocclusions in the mandibular central incisor, mandibular lateral incisor, and mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic.

Alternative Hypothesis: There is a significant difference between the Class I, Class II div 1, Class II div 2, and Class III molar malocclusions in the mandibular central incisor, mandibular lateral incisor and mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic.

5. Is there a significant difference (p=0.05) between Class I, Class II div 1, Class II div 2, and Class III skeletal malocclusions in the maxillary central incisor, maxillary lateral incisor and maxillary canine collum angles in a sample of orthodontic patients in the SDM clinic?

   Null Hypothesis: There is no significant difference between the Class I, Class II div 1, Class II div 2, and Class III skeletal malocclusions in the maxillary central incisor, maxillary lateral incisor, and maxillary canine collum angles in a sample of orthodontic patients in the SDM clinic.

   Alternative Hypothesis: There is a significant difference between the Class I, Class II div 1 and Class II div 2, and Class III skeletal malocclusions in the maxillary central incisor, maxillary lateral incisor and maxillary canine collum angles in a sample of orthodontic patients in the SDM clinic.

6. Is there a significant difference ($p=0.05$) between Class I, Class II div 1, Class II div 2, and Class III skeletal malocclusions in the mandibular central incisor, mandibular lateral incisor and mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic?

   Null Hypothesis: There is no significant difference between the Class I, Class II div 1, Class II div 2, and Class III skeletal malocclusions in the mandibular central incisor, mandibular lateral incisor and mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic.

   Alternative Hypothesis: There is a significant difference between the Class I, Class II div 1, Class II div 2, and Class III skeletal malocclusions in the mandibular central incisor, mandibular lateral incisor, and mandibular canine collum angles in a sample of orthodontic patients in the SDM clinic.

## Chapter 2 : Literature Review

On examination of the morphology of a tooth, it is apparent that the tooth can be divisible into two major proportions: the crown and the root. Morphological variations of the crown such as the cervical width, the mesiodistal width, and the length have been observed between various samples of the same tooth (Mavroskoufis, 1980). These variations however, are understood to be largely under the influence of genetic control. In contrast, the root structure of a tooth has been found to have a higher propensity for influence by factors in the environment. The root of a tooth has often been quite variable, with poor correlation to crown and jaw structures. In addition, the number of roots has varied significantly amongst teeth of the same classification. As such, the quantification of crown to root morphology may have a significant effect in various areas of dental treatment planning.

In dentistry, the maxillary and mandibular central incisors, lateral incisors and canines make up the zone of esthetics. This area is usually of primary concern for the dental patient and utmost care is involved in the esthetics, restoration and alignment of these teeth. When the collum angle is not zero, restorative issues may arise. In restoring a tooth with a large collum angle, core build-ups may be a concern as the post may not align in the same axes in which the core is to be constructed. Similarly, when an implant is placed, the angle of placement usually follows that of the long axis of the previous root. Since the crown must be restored so that it is in alignment with the crown axis, a large collum angle will dictate the use of an angular abutment. Shen et al. indicated that when an angular abutment is used, the stress is concentrated on the buccal surface of the fixture. By doing so, it may be contributing to the etiology of gingival recession (Shen, 2012). Although there are several implications of the collum angle in relation to general dentistry, the literature is limited. Notably, the majority of the literature regarding the collum angle is found almost exclusively in the field of orthodontics.

As the proclaimed “father of modern orthodontics,” Edward Angle introduced the edgewise appliance in 1928 (Phillipe, 2008). The introduction of this apparatus allowed for ease in clinical manipulation and better control of teeth in three dimensional space. Its advent was hailed as a major advancement in the field of orthodontics. However, the major downfall of the appliance, was that the brackets were designed universally for all teeth, characterizing the brackets as, “non-programmed” (Andrews, 1989). The implication of a non-programmed bracket as such, was that complex and laborious wire bending was necessary to achieve satisfactory occlusion.

In 1970, Dr. Lawrence Andrews introduced The Straight Wire Appliance to more efficiently achieve the six keys of normal occlusion. The “programmed brackets” introduced in his Straight Wire Appliance corrected for the weaknesses in the edgewise appliance by eliminating the need to place extensive bends in finishing wires (Andrews, 1989). Notably, each bracket was designed to be tooth specific, with tip, torque, and offset built into the prescription of the bracket.

During its development, the Straight Wire Appliance was designed with its fundamental basis in the “Six Keys of Normal Occlusion” (Andrews, 1972). As the third key, it is evident that crown inclination is of great importance in developing ideal post treatment orthodontic results. While studying 120 casts of non-orthodontic patients with normal occlusion, Dr. Lawrence Andrews determined the average crown inclination of each tooth. This was done by drawing a line perpendicular to the occlusal plane and intersecting it with a line tangent to the facial surface of the clinical crown (Andrews, 1989). In this way, Dr. Andrews was able to define crown inclination, or in other words, assess torque values for each tooth.

Although these measurements have undoubtedly contributed to the development of the Straight Wire Appliance, the angular difference between the longitudinal axes of the crown and the root were not addressed. In fact, Dr. Andrews defines crown inclination as the "labiolingual or buccolingual inclination of the long axis of the crown, not to the inclination of the long axis of the entire tooth," (Andrews, 1972). The disregard for the longitudinal axis of the root may indicate the assumption of a negligible crown to root angulation. Therefore, it is conceivable that the premise of a zero degree collum angle has been propagated by its omission.

In orthodontics, cephalometric analyses are commonly used to aid in diagnosis and treatment planning. Consequently, Steiner advocated using cephalometric templates to allow for better tracing accuracy and reproducibility (Steiner, 1959). In the vast majority of cephalometric templates, the longitudinal axis of a maxillary incisor is correlated with other reference lines, representing the inclination of the maxillary incisor and the interincisal angle (Carlsson, 1973). As mentioned before, Bjork defined this longitudinal axis as the line passing through the incisor superioris and the apex of a tooth

(Figure 2). However, Bryant et al. notes that the aforementioned longitudinal axis may be erroneous, as it does not account for the collum angle and its corresponding crown to root angulation. He states that when a line is drawn through the proximal radiogram of a central incisor, the longitudinal axis may not pass through a line bisecting the cementoenamel junction (Figure 2). In this way, the collum angle of the radiographed tooth may not be zero and crown to root angulations are not apparent on cephalograms, (Delivanis, 1980). Although lateral cephalometric templates are standardized, it is apparent that morphological variations, such as the collum angle, may not be accounted for in the standardization process.

In assessing collum angles, Carlsson and Ronnerman measured the crown to root angulation of teeth with varying levels of abrasion. They used 88 extracted maxillary central incisors and projected the image of each tooth onto tracing paper. The projected image was then traced and its collum angle measured by hand. They found that the longitudinal axis of the crown varied in its situation to the root axis both facially and lingually (Carlsson, 1973). In Taylor's study, a facially situated crown was more common (Taylor 1969), whereas, Sicher and Du Brul, found the opposite conclusion (Sicher and Du Brul, 1970). Carlsson subsequently attributed the variation in collum angles to the degree of abrasion and its tendency to shift the incisor superiorus facially. Although the collum angle was shown to vary in this study, the study appears to be problematic in its characterization of abraded teeth. Bauer suggested that the use of a distorted incisor superioris is questionable and is an ineffective measure of collum angles in a population (Bauer, 2014).

To characterize the collum angle in a population, several authors used Angle's molar classification to better categorize the collum angle. In Bryant et al.'s study, there was a significant difference in collum angles in Class II div 2 malocclusions when compared to Class II div 1 and Class III patients. In addition, they found that the collum angle had a range of 25.5 degrees. This portion of his study was conducted by using maxillary central incisors traced from lateral cephalograms.  One hundred samples were used with 25 in each molar classification. In a similar study, Delanis and Kuftinec used lateral cephalometric x-rays with 53 Class II div 2 patients and 53 samples of various malocclusions as a comparison group. They found that Class II div 2 malocclusions exhibited larger collum angles than the control group. This finding was again, confirmed by Israr et al., who also found a significant difference in collum angles in Class II div 2 malocclusions. In Srinivansan's study, it was proposed that lower lip pressure and its position on the maxillary central incisor crown was the cause of the larger collum angles in Class II div 2 patients. Correspondingly, it has been suggested that the lingually "bent" maxillary central incisor position, characteristic of Class II div 2 malocclusions, is the reason for abnormal collum angles in such patients (Bryant, 1984).   It has therefore, been postulated that the deviant collum angles found in Class II div 2 patients may be a contributing factor to the development of deep bites in these malocclusions.

Unlike the previous studies, Harris et al. compared collum angles of maxillary central incisors to Class I, II, and III malocclusions, combining the divisions of the Class II malocclusions. By using 79 samples and the same protocol as Bryant et al., he found that Class I malocclusions had a mean collum angle of 5.6 degrees, Class II malocclusions had a mean collum angle of 6.1 and Class III malocclusions had a mean collum angle of 11.9 degrees. Although the Class I and Class II malocclusions were not significantly different, there was a significant difference between Class III malocclusions. They postulated that this difference may be due to the compensatory effect of lingually torqued maxillary incisors being restrained within the mandibular arch.

In contrast to the previous studies in which only maxillary centrals were measured, Germane et al. measured collum angles in extracted maxillary and mandibular canines. This study was done by acquiring 100 extracted maxillary canines and 70 mandibular canines, and radiographing the extracted teeth. The authors subsequently measured the collum angles but did not classify the teeth by molar classification. They found that the average maxillary canine collum angle was -2.46 degrees, indicating that the root of the maxillary canine was facial to the crown axis. As for the mandibular canine, the collum angle was measured to be 4.83 degrees, indicating that the mandibular canine root was lingual to the crown axis. By characterizing the collum angles in maxillary and mandibular canines, Germane was the first to measure the collum angles of teeth other than the maxillary central incisors. However, there was no categorization of the canines by Angle's molar classification, making the values obsolete in terms of generalization to normal occlusion.

With the advent of Cone Beam Computed Tomography, measurements of all teeth are made possible. In previous studies, the collum angles were measured primarily by tracing lateral cephalometric radiograms. This procedure however, precluded the measurements of lateral incisors and canines due to issues with superimposition. For the same reason, mandibular teeth were very difficult to measure. The other method used in prior literature, employed the use of extracted teeth. However, this is problematic since teeth which are extracted are not usually classified by molar classification and are difficult to obtain in large volumes. By using CBCT, a more efficient and practical method of measuring collum angles will be utilized. Therefore, this study will be the first to quantify the collum angles of all maxillary and mandibular anterior teeth with regard to their molar and skeletal classifications.

# Chapter 3: Methodology

Protocol #844006-1 has undergone Administrative Review by the UNLV Biomedical IRB and has received notice of excluded activity. The Office of Research Integrity - Human Subjects at the University of Nevada, Las Vegas has determined that this protocol does not meet the definition of human subjects research under the purview of IRB according to federal regulations (Appendix A).

## Sampling Procedure

This study was designed as a cross-sectional, retrospective investigation in order to measure the collum angles of pre-orthodontic patients with various malocclusions. The sample used in this study consisted of 412 CBCT scans obtained from January 2013 to January 2016 at the University of Nevada Las Vegas, Department of Orthodontics and Dentofacial Orthopedics. The CBCT data was taken on the Hitachi Medical Corporation CB MercuRay by a single radiographic technician trained in the use of the aforementioned radiographic machine. The CBCT machine was set at the following parameters of: 100 kilovolts, 15 milliamperes, a 10 second exposure time, 193mm field of view, a matrix of 512 x 512 voxels and a resolution of 0.38mm.

The data obtained from the CBCT scans were stored in the Digital Imaging and Communications in Medicine (DICOM) format on a password protected external hard drive located at the UNLV School of Dental Medicine. Invivo 5.4.5 for Macintosh was used for volumetric rendering of the sample CBCT scans (Anatomage, San Jose, CA). Measurements for each tooth were made with the linear and angular measurement tools provided in the software.

The CBCT scans were cross referenced with their corresponding patient charts to ensure that all clinical and treatment plan forms, in addition to clinical photos were present. From these records, each patient was organized into two different categories. These categories were subsequently reaffirmed by the examiner to ensure that categorization was standardized throughout the study. The following categories were characterized as follows:

Category I: Angle's Molar Classification

Category I was classified according to the American Board of Orthodontics standards for molar classification as provided in the Discrepancy Index Guidelines (ABO DI Index, 2016). Since patients may have different molar classifications when comparing the left and right sides, each side was considered a different sample.

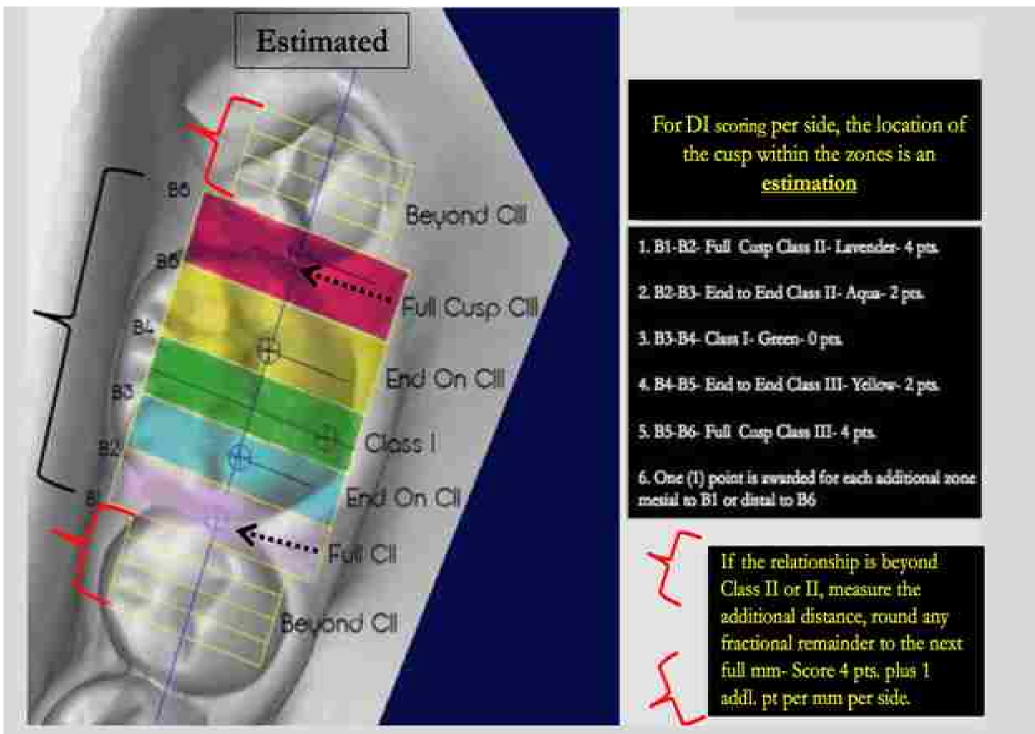


*Figure 3.1. American Board of Orthodontics standards for molar classification as provided in the Discrepancy Index Guidelines. Adapted from "The Discrepancy Index Scoring," by The American Board of Orthodontics Website.*

*Group 1: Class I malocclusion*

A Class I molar malocclusion was defined as having the mesial buccal cusp of the upper first molar contacting within the buccal groove of the lower first molar to approximately halfway between the adjacent cusps (Figure 3.2). This area is represented by the green zone in Figure 3.1. This group is not to be confused with Class I normal occlusion as it encompasses issues such as crowding, spacing, misalignment of teeth, crossbites and other factors that may motivate a patient to seek orthodontic treatment regardless of a normal molar position (Figure 3.3).

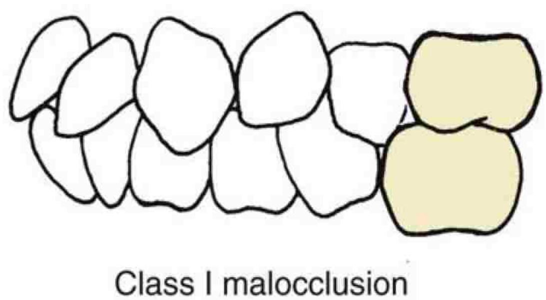


*Figure 3.2. Class I molar malocclusion. Adapted from "Contemporary Orthodontics 5th Edition," by William Profitt, Henry Fields and David Sarver, 2013, p.4. Copyright 2013 by Elsevier Inc.*

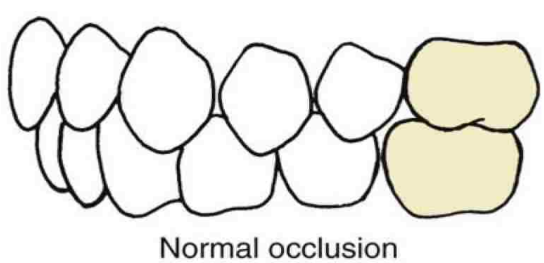


*Figure 3.3. Class I molar normal occlusion. Adapted from "Contemporary Orthodontics 5th Edition," by William Profitt, Henry Fields and David Sarver, 2013, p.4. Copyright 2013 by Elsevier Inc.*

*Group 2: Class II div 1 malocclusion*

A Class II div 1 molar malocclusion was defined as having the mesial buccal cusp of the upper first molar contacting the area mesial to half a cusps width past the buccal groove of the lower first molar (Figure 3.4). This area is represented by the lavender and aqua areas in Figure 3.1. In this study, Class II div 1 encompasses all categories of a Class II molar malocclusions that do not fall into the category of Class II div 2.

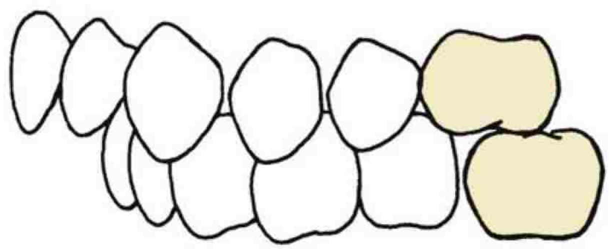


*Figure 3.4 Class II div 1 molar malocclusion. Adapted from "Contemporary Orthodontics 5th Edition," by William Profitt, Henry Fields and David Sarver, 2013, p.4. Copyright 2013 by Elsevier Inc.*

*Group 3: Class II div 2 malocclusion*

A Class II div 2 molar relationship was defined as having the mesial buccal cusp of the upper first molar contacting the area mesial to half a cusps width past the buccal groove of the lower first molar. This area is represented by the lavender and aqua areas in Figure 3.1. This classification must have the aforementioned molar relationship, in addition to retroclination of the central incisors, proclination of the lateral incisors, and a deep bite (Figure 3.5). These additional factors were confirmed visibly by the examiner with the use of the patient photos and the clinical exam form which indicated if the overbite was greater than 80%.

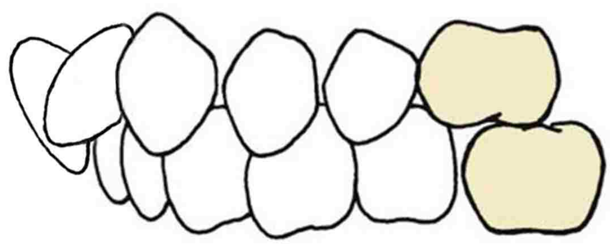


*Figure 3.5. Class II div 2 molar malocclusion.*

*Group 4: Class III malocclusion*

A Class III molar relationship was defined as having the mesial buccal cusp of the upper first molar contacting the area distal to half a cusps width past the buccal groove of the lower first molar (Figure 3.6). This area is represented by the red and yellow areas in Figure 3.1.

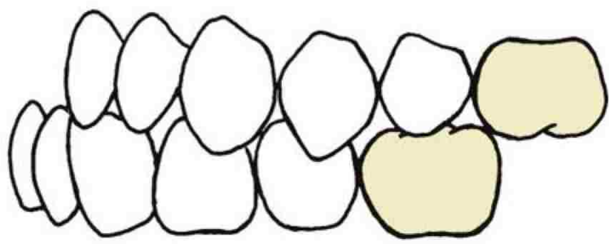


*Figure 3.6. Class III molar malocclusion. Adapted from "Contemporary Orthodontics 5th Edition," by William Profitt, Henry Fields and David Sarver, 2013, p.4. Copyright 2013 by Elsevier Inc.*

Category II: Skeletal Classification

Category 2 characterized the anterior-posterior relationship between the maxilla and the mandible. It was classified primarily based on the skeletal classification indicated on the diagnosis and treatment planning forms in the patient charts. Since the skeletal classification for either side of a patient does not change due to issues with superimposition on a lateral cephalogram, each side was classified with the same skeletal classification. No attempt was made to further standardize the classifications from what was stated in the patient chart, except in the Class II div 2 category. These classifications were then subject to the following standardization guidelines below.

*Group 1: Skeletal Class I*

A Class I skeletal classification was defined as having an orthognathic relationship between the maxilla and the mandible.

*Group 2: Skeletal Class II div 1*

A Class II skeletal classification was defined as having either a retrognathic mandible, a prognathic maxilla or both.

*Group 3: Skeletal Class II div 2*

A Class II div 2 skeletal classification relationship was defined as having either a prognathic maxilla, a retrognathic mandible or both. In addition, this group was classified with the following parameters: a Frankfort mandibular plane angle under 25 degrees, an U1-SN less than 95 degrees, and an ANB less than 6 degrees.

*Group 4: Skeletal Class III*

A Class III skeletal classification was defined as having a prognathic mandible, a retrognathic maxilla or both.

After characterizing each patient by their molar and skeletal classifications, the corresponding CBCT DICOM files were anonymized by converting all identifiable information into a random number. This number was recorded into an excel spreadsheet in which all other information pertinent to the patient was recorded.

Subjects with poor radiographic quality, primary anterior dentition, developing roots, and worn incisal edges were excluded from this study. Other exclusion criteria included patients with severely rotated or malformed anterior teeth, patients with previous orthodontic treatment, and patients without full records. After the exclusion criteria was fulfilled, the study was left with 326 subjects. Since the right and left sides of the dental arches were classified as a distinct sample, the total sample size used in this study was 652.

**Procedure for Natural Head Position Orientation**

All CBCT scans were standardized by orienting the head in natural head position in three planar views. This first step involved finding the odontoid process of the atlas bone (C2) in the axial view. The head was then aligned such that the midline of the maxilla and the odontoid process would lie equally bisected by a vertical line (Figure 3.7).

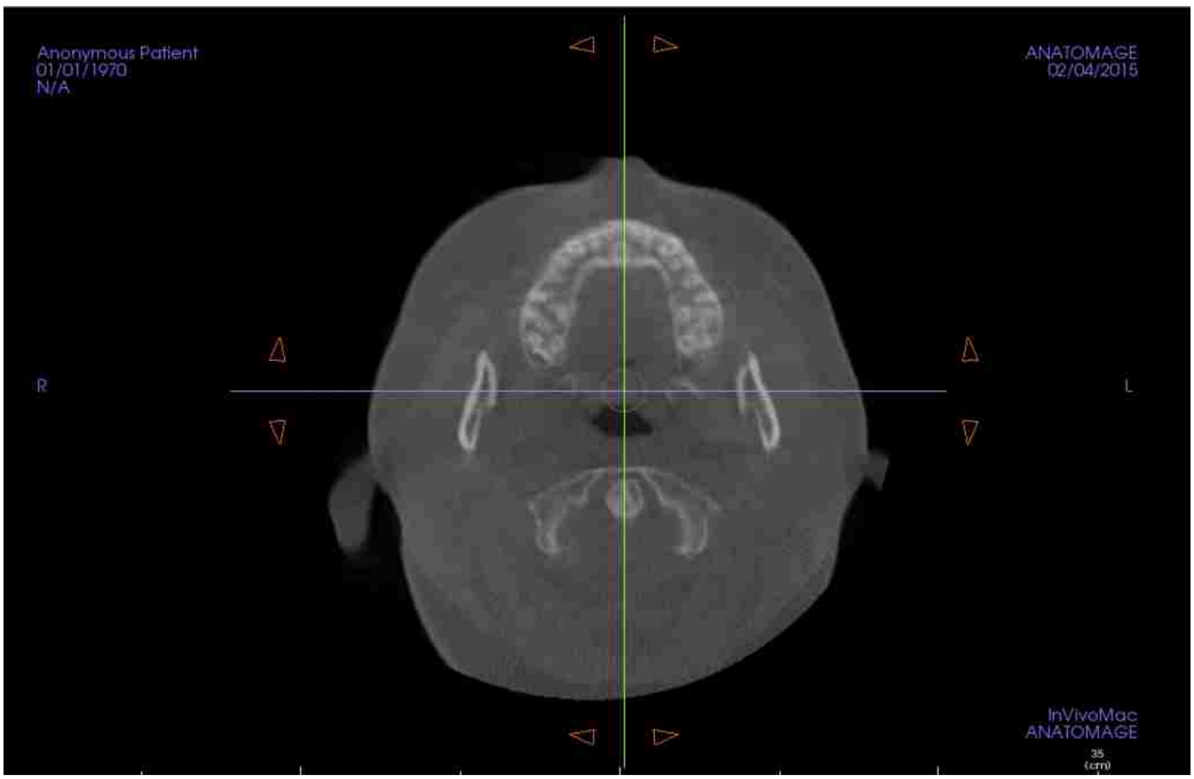


*Figure 3.7. Standardized head position oriented in the axial view.*

In the sagittal section, the head was oriented so that the line connecting the anterior nasal spine to the posterior nasal spine would be parallel with the bottom on the monitor. The intended alignment is in reference to the anatomical hard palate (Figure 3.8).

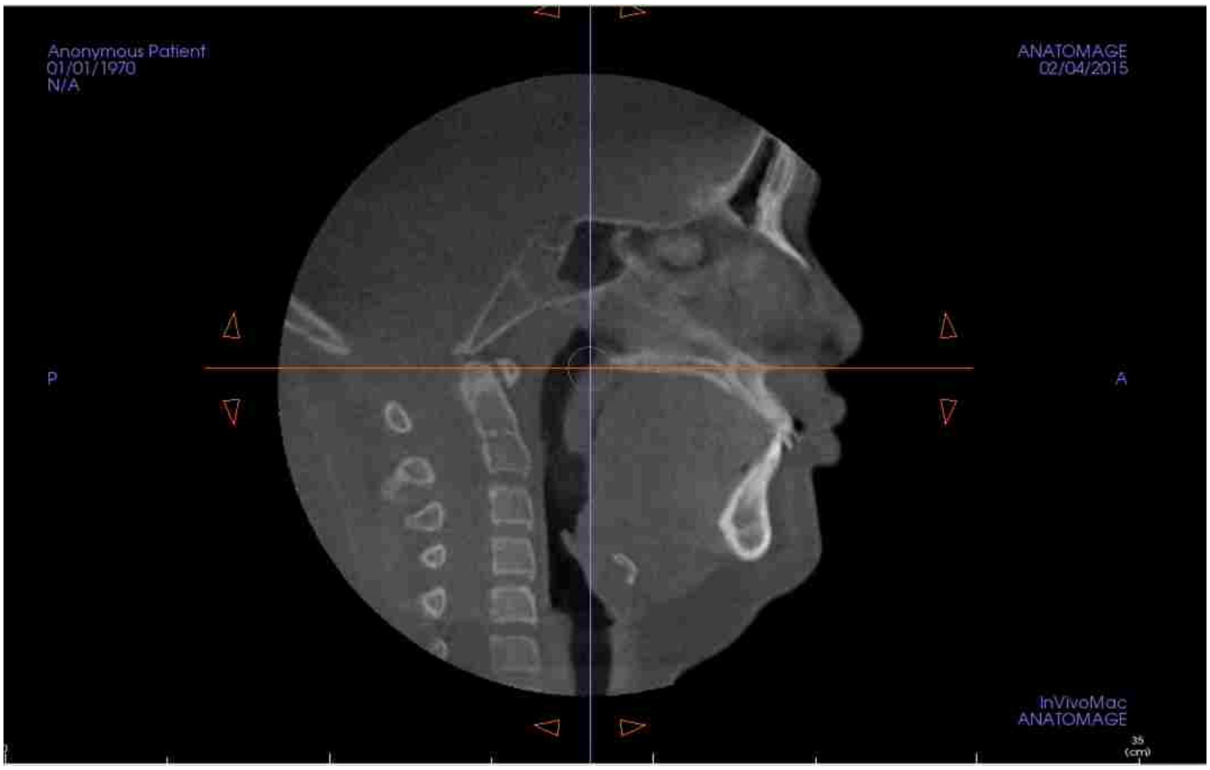


*Figure 3.8. Standardized head position oriented in the sagittal view.*

Finally, the coronal section is aligned by approximating the mandibular condyles so that their size and shape are relatively equal. The head is then rotated so that a vertical line bisects the midline of the oropharyngeal airway (Figure 3.9).

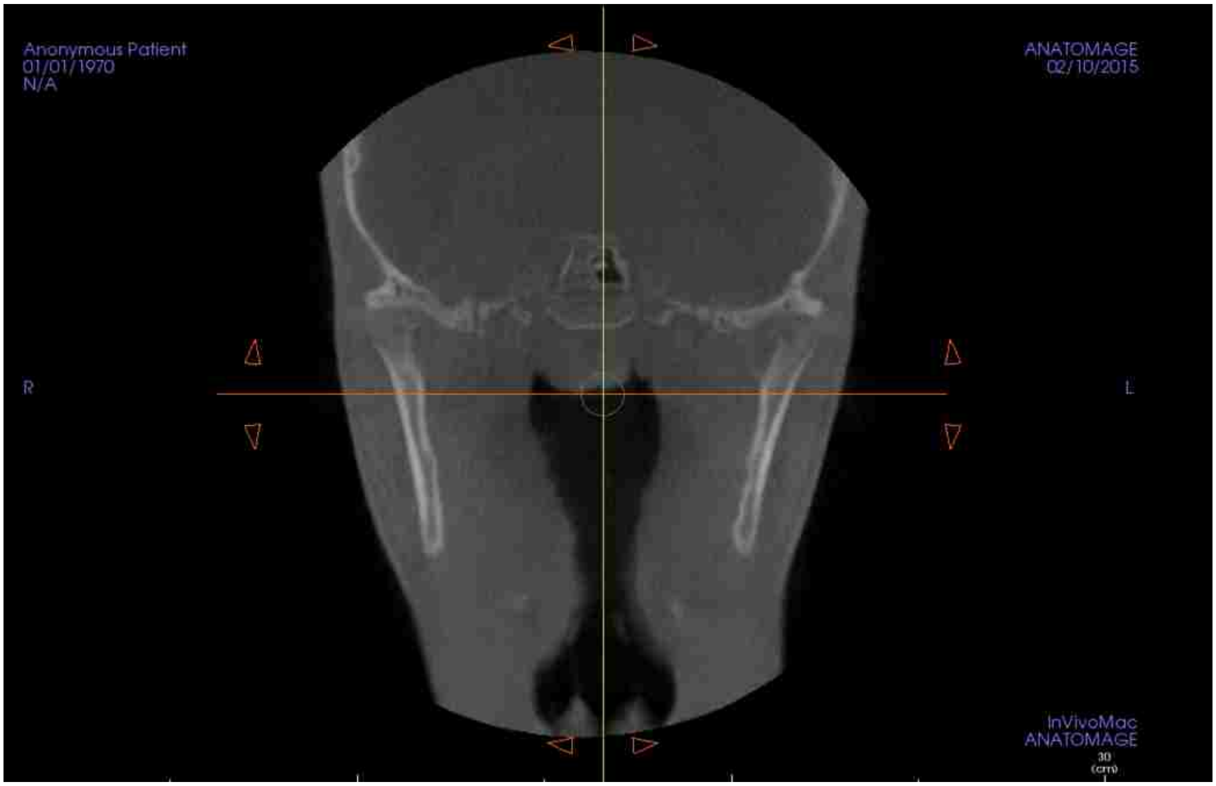


*Figure 3.9. Standardized head position oriented in the coronal view.*

**Adjustment for Brightness and Contrast**

The brightness of each scan was adjusted by finding a sagittal slice in which the maxillary sinus was clearly visible. The blackness of the maxillary sinus was then adjusted until the blackness of the peripheral background was identical (Figure 3.10).

*Figure 3.10. Adjustment for blackness. The blackness of the maxillary sinus is identical to that of the periphery.*

In the adjustment for contrast, the same sagittal slice is used. The contrast was then adjusted so that the detail in the mandibular trabeculae was most clearly defined (Figure 3.11).

*Figure 3.11. Adjustment for contrast. Detail in the mandibular trabecular is most clearly defined.*

**Measurement of the Crown to Root Angle (x)**

The CBCT scans were rendered using InVivoMac 5.4.5. Within this software, the "Arch Section" tab was used to visualize the axial section of the maxilla or the mandible. The slices were then set to have a thickness of 2.0 mm with slice increments set at 0.1mm. The range was then adjusted to only view the maxillary teeth when measuring the upper teeth. For the mandibular teeth, the range was adjusted to the full length of the mandibular teeth. The axial slice with the best view of the maxillary anterior teeth was then chosen. The chosen slice should show the contacts of the anterior teeth, the pulp space of each tooth, and the general triangular anatomical shape of the central and lateral incisors (Figure 3.12). The same procedure was used for the mandibular teeth.

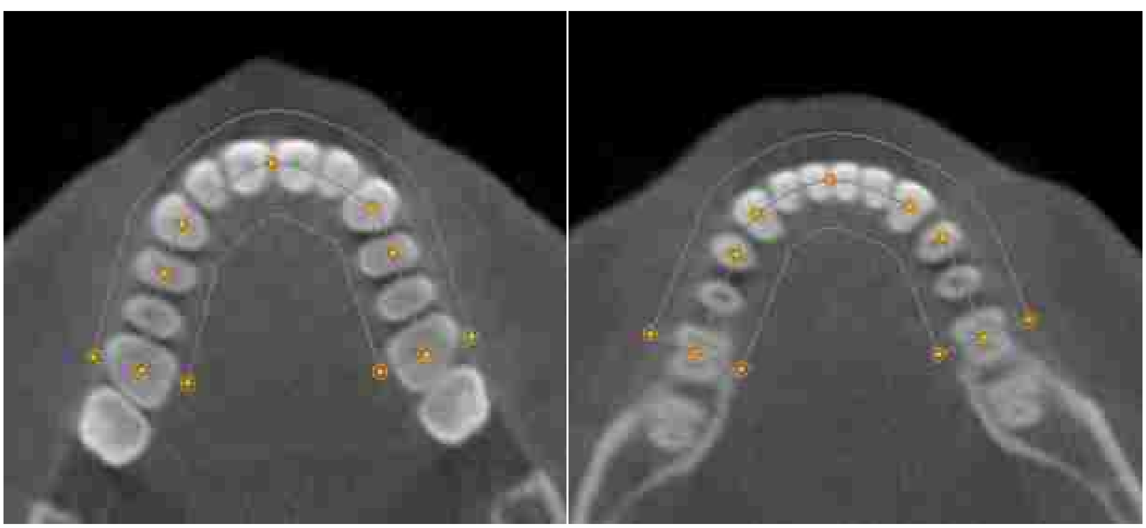

*Figure 3.12. Arch sections of the maxilla and mandible chosen for measurements.*

The orange cursors are then moved to the mesial and distal of the tooth to be measured such that slice is centered on the midline of the tooth (Figure 3.13). In this way, the sagittal slice created will be directly centered on the longitudinal axis of the tooth (Figure 3.14). This is especially important, as the level of the cementoenamel junction moves more incisally as you move towards the mesial and distal.

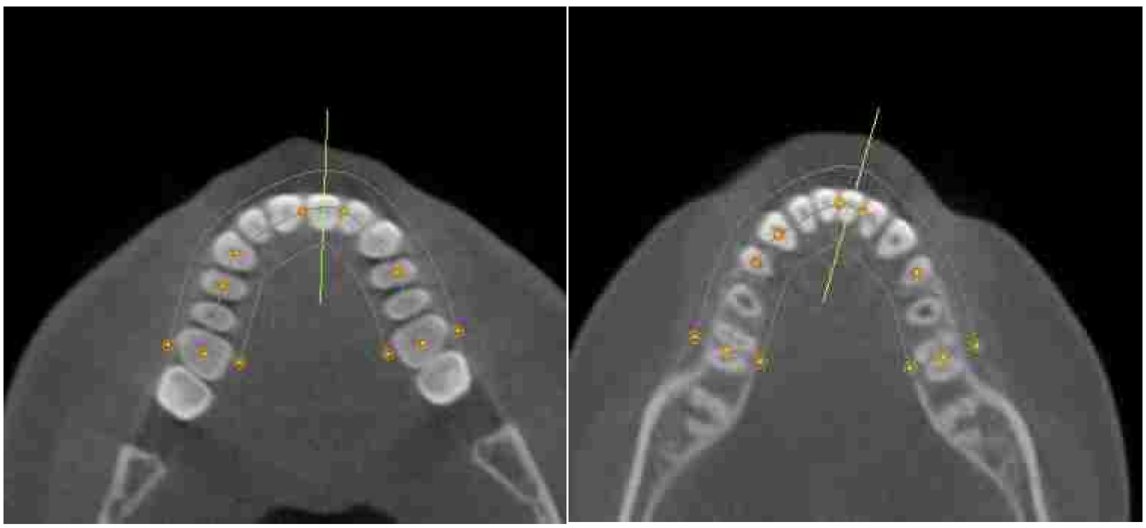

*Figure 3.13. Orienting the sagittal slice so that it is centered on the midline of the tooth.*

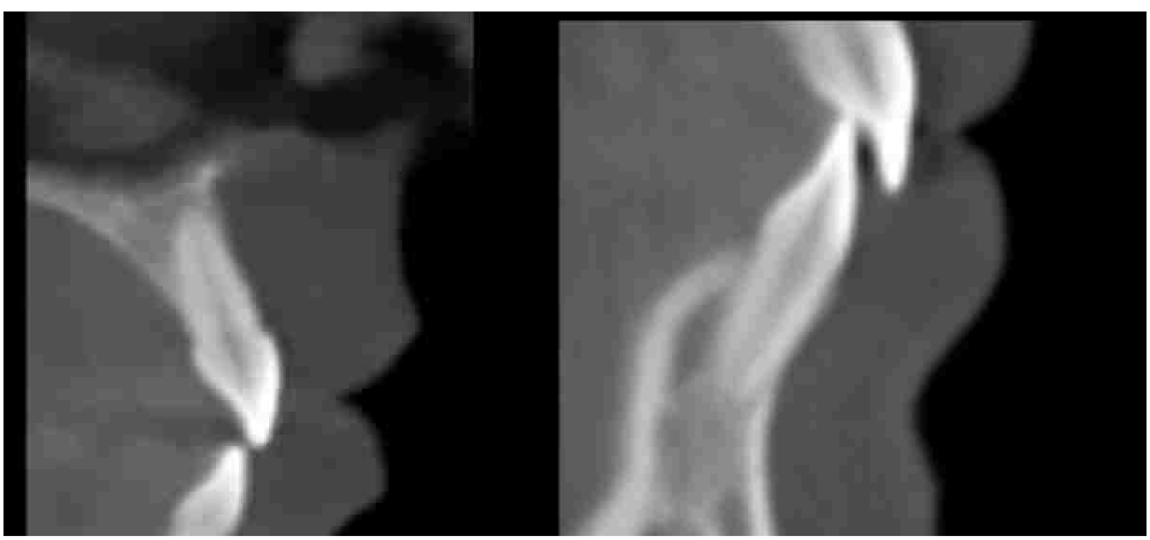

*Figure 3.14. The resulting sagittal slices of a maxillary and mandibular central incisor positioned at the center of the longitudinal axis.*

Once the sagittal slice has been created and centered along the longitudinal axis, the tooth can then be measured. The crown to root angle (x) is measured by connecting three points. The first point is the incisor superioris, representing the undamaged incisal edge (Rakosi, 1982). The second point is found by bisecting a line connecting the facial cementoenamel junction and the lingual cementoenamel junction. In this study, we will call this, the bisected CEJ point. Finally, the third point is the characterized by the anatomical root apex. By connecting all three points, the crown to angle (x) is created (Figure 3.15).

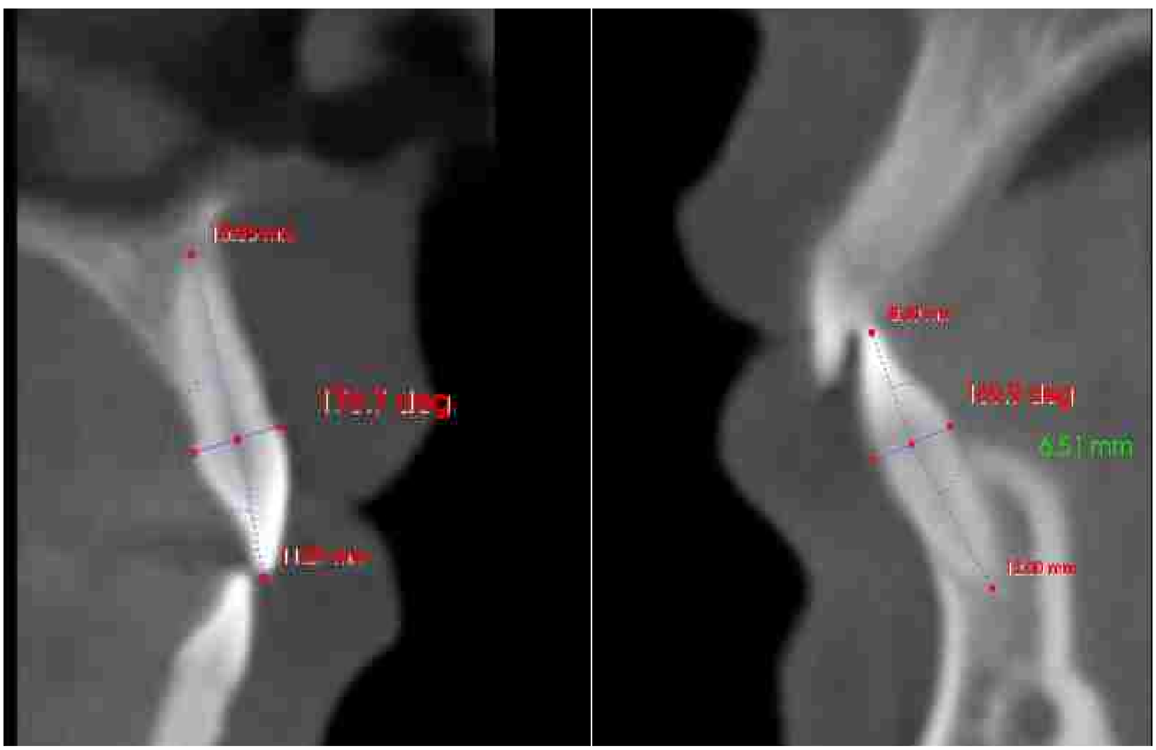


*Figure 3.15. The crown to root angle (x). The angle is measured according to the incisor superioris, the bisected CEJ point, and the root apex.*

The collum angle is the supplementary angle of the crown to root angle (Figure 3.16). It is thereby, calculated by subtracting the crown to root angle from 180 degrees. As such, the formula for the collum angle is 180-x. A positive collum angle represents a lingually inclined crown in relation to the root axis, whereas a negative collum angle represents a labially inclined crown in comparison to the root axis. A zero degree collum angle represents a completely straight tooth in which the longitudinal axes of the crown and root form a single line (Figure 3.17).

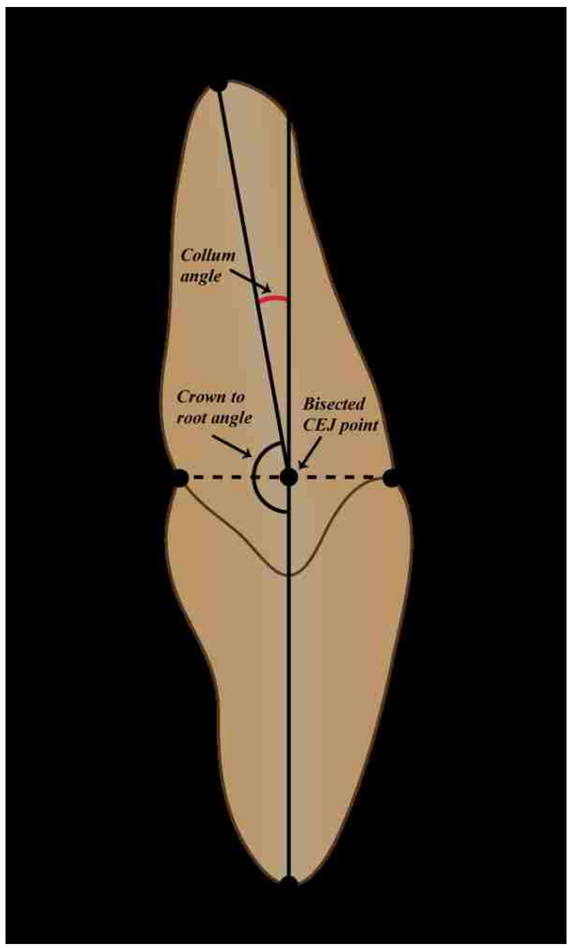


*Figure 3.16. The collum angle. It is the supplementary angle of the crown to root angle (x), calculated as 180-x.*

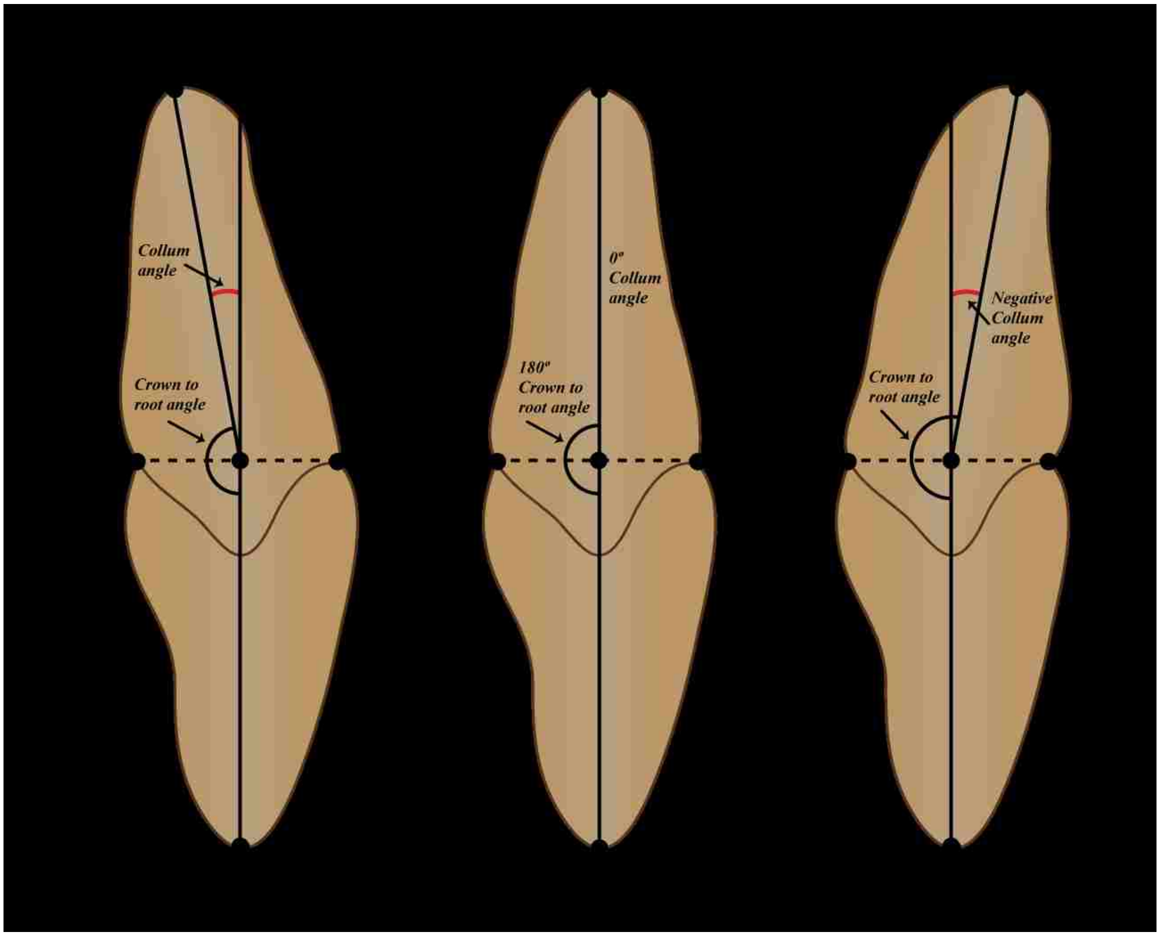


*Figure 3.17. Positive, zero degree and negative collum angles. A positive collum angle represents a lingually inclined crown when compared to the root axis. A zero degree collum angle indicates a straight tooth and a negative collum angle indicates a facially inclined crown in relation to the root axis.*

**Statistics Methodology**

The data was formatted in an excel spreadsheet and submitted to a statistician for data analysis in SPSS. The following methods were used to analyze the data collected in this study.

<u>Determining Mean Collum Angles (Research Question 1)</u>

*Mean determination.* The mean was determined by averaging all the collum angles for each anterior tooth, regardless of malocclusion. Mean collum angles were then determined for the maxillary and mandibular centrals, laterals and canines.

<u>Determining Differences from Zero (Research Question 2)</u>

*One-Sample t-test.* The one-sample t-test was used to compare the overall mean of each tooth to the hypothetically assumed value of zero degrees. This test did not take into consideration any of the categorization methods used except the type of the tooth being measured.

<u>Determining Mean Collum Angles for Molar and Skeletal Classfications (Research Question 3,4,5, and 6)</u>

*Kruskal-Wallis One-way Analysis of Variance (ANOVA).* This non-parametric statistical test was used to assess whether the samples used to answer these research questions originated from the same distribution. This test was selected because there were two or more independent means of equal or different sample sizes selected from a non-random sample. The results were used to determine if there were significant differences between each tooth for each molar classification, and again for each tooth for the skeletal classifications. If significant differences were found, then the Bonferroni Post-Hoc Test was applied to determine precisely between which molar classification and/or which skeletal classification the difference existed.

Difference between Collum Angle Means in Molar and Skeletal Classifications

**Comparison of Two Means**. A comparison of two means was run to determine if the mean collum angles found in the molar classifications were significantly different from mean collum angles found in the skeletal classification categories. The significance was tested at a p-level of 0.05.

Accuracy in Measurements

**Intra-rater Reliability.** To ensure the reliability of the measures obtained from one observer, intra-rater reliability was computed. Test-retest was used to determine if the same results would be obtained. The results were then computed using Pearson Correlations to determine if the correlation was high between the first observation and the second observation. The Kappa statistic interpretation based on “Practical Statistics for Medical Research” was used, (Altman, 1990). The following table was used to determine the internal consistency of the two measures (Table 3.1).

Table 3.1
*Kappa Statistic Interpretation*

| Agreement | Range |
|---|---|
| Very good agreement | 0.80 - 1.00 |
| Good Agreement | 0.60 - 0.80 |
| Moderate Agreement | 0.40 - 0.60 |
| Fair Agreement | 0.20 - 0.40 |
| Poor Agreement | <0.20 |

# Chapter 4: Results

## Mean Collum Angle per Anterior Tooth

Table 4.1
*Mean Collum Angles per Anterior Tooth*

| Tooth | Maxillary Central Incisor (Standard Deviation) | Maxillary Lateral Incisor (Standard Deviation) | Maxillary Canine (Standard Deviation) | Mandibular Central Incisor (Standard Deviation) | Mandibular Lateral Incisor (Standard Deviation) | Mandibular Canine (Standard Deviation) |
|---|---|---|---|---|---|---|
| N | 610 | 565 | 478 | 608 | 590 | 530 |
| Mean | 4.13 (6.17) | 6.20 (6.53) | 1.11 (6.82) | 5.94 (3.71) | 6.49(4.32) | 7.82 (4.73) |
| Range | -23.2 – 22.7 | -16.6 – 32.8 | -19.1 – 23.1 | -9.6 – 10.4 | -9.6 – 22.3 | -8.0 – 22.7 |

The mean collum angle for the maxillary central incisor was 4.13 degrees. The mean for the maxillary lateral incisor was 6.20 degrees and the mean for the maxillary canine was 1.11 degrees. Subsequently, the mean mandibular central incisor collum angle was 5.94 degrees, whereas the mean mandibular lateral incisor collum angle was 6.49 degrees. Finally, the mean mandibular canine collum angle was 7.82 degrees. The largest collum angle was found in the mandibular canine and the smallest collum angle was found in the maxillary canine.

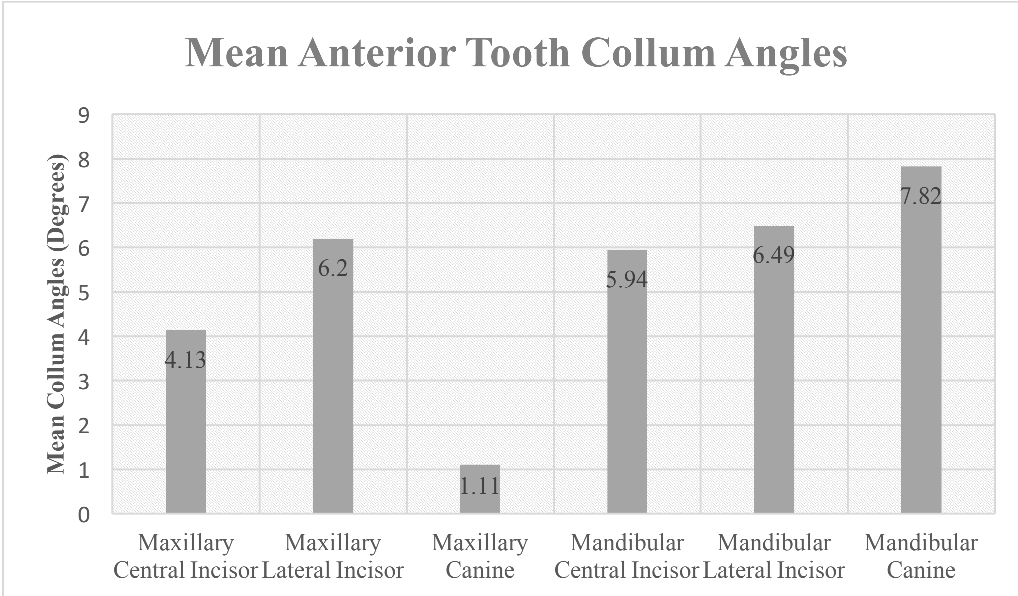


*Figure 4.1 Mean anterior tooth collum angles.*

**Difference from Zero**

A one sample t-test was used to test if the mean collum angles for each type of anterior tooth was significantly different from zero. The results of this test demonstrated that the collum angles for each anterior tooth were significantly different. Consequently, the collum angles of each tooth were significantly different at a p value of 0.05.

**Molar Classification Analysis**

A one-way analysis of variance was used to compare the collum angles of each tooth to each molar classification. The statistics were run with a 95% confidence interval and a p value of 0.05.

Table 4.2
*Mean Anterior Tooth Collum Angles per Molar Classification*

| Tooth | Molar Classsification | N | Mean Collum Angle in Degrees (Standard Deviation) |
|---|---|---|---|
| Upper Central | Class I | 301 | 3.88 (5.44) |
| | Class II div 1 | 166 | 4.30 (6.35) |
| | Class III | 108 | 3.39 (7.39) |
| | Class II div 2 | 35 | 7.86 (6.10)* |
| | Total | 610 | 4.13 (6.17) |
| Upper Lateral | Class I | 281 | 6.38 (5.48) |
| | Class II div 1 | 144 | 6.32 (7.36) |
| | Class III | 106 | 6.78 (7.61) |
| | Class II div 2 | 34 | 2.47 (6.14)* |
| | Total | 565 | 6.20 (6.53) |
| Upper Canine | Class I | 243 | 1.41 (5.93) |
| | Class II div 1 | 117 | 1.03 (7.33) |
| | Class III | 93 | 0.41 (7.96) |
| | Class II div 2 | 25 | 1.18 (8.06) |
| | Total | 478 | 1.11 (6.82) |
| Mandibular Central | Class I | 302 | 6.04 (3.52) |
| | Class II div 1 | 162 | 5.43 (3.91) |
| | Class III | 111 | 6.25 (3.86) |
| | Class II div 2 | 33 | 6.45 (3.90) |
| | Total | 608 | 5.94 (3.71) |
| Mandibular Lateral | Class I | 289 | 6.33(4.15) |
| | Class II div 1 | 161 | 6.16(4.36) |
| | Class III | 106 | 6.95(4.88) |
| | Class II div 2 | 34 | 7.97 (3.41) |
| | Total | 590 | 6.49(4.32) |
| Mandibular Canine | Class I | 266 | 7.66 (4.64) |
| | Class II div 1 | 131 | 7.40 (4.24) |
| | Class III | 103 | 8.50 (5,43) |
| | Class II div 2 | 30 | 8.75 (4.80) |
| | Total | 530 | 7.82 (4.73) |

*These groups were significantly different at a p-value of 0.05.

Maxillary Central Incisors

The mean collum angle for the maxillary central incisors came out to be 3.88 degrees in the Class I group. This was not statistically significant from the mean collum angles in Class II div 1 and Class III patients, which were 4.30 degrees and 3.39 degrees respectively. There was however, a statistical difference between all the mean collum angles in each classification when compared to the Class II div 2 malocclusions.

Maxillary Lateral Incisors

The mean collum angle for the maxillary lateral incisors appeared to be larger than the maxillary central incisors with an exception of the Class II div 2 group. None of the classes were significantly different from each other except for the Class II div 2 group. The Class II div 2 group had smaller collum angles for the lateral incisors with a mean of 2.47 degrees. When comparing all the different malocclusions to the Class II div 2 group, the Class II div 2 group was significantly different from all the other malocclusions at a p-level of 0.05.

Maxillary Canines

The maxillary canines when compared to all the anterior teeth had smaller mean collum angles. The Class I group had a mean of 1.41 degrees, the Class II div 1 group had a mean of 1.03 degrees, the Class III group had a mean of 0.41 degrees and the Class II div 2 group had a mean of 1.18 degrees. Unlike the previous teeth discussed, there was no statistical difference in the upper canines amongst the various classifications.

Mandibular Central Incisors

The mandibular central incisors in the Class I group had a mean of 6.35 degrees. The Class II div 1 group had a slightly smaller collum angle with a mean of 5.43 degrees. The Class III and Class II div 2 groups had a more similar mean to the Class I group with 6.25 degrees and 6.45 degrees respectively. None of the malocclusions were significantly different from the other.

Mandibular Lateral Incisors

The collum angle for the Class I group was 6.33 degrees. This was fairly similar to the Class II div 1 and III groups which were 6.16 degrees and 6.95 degrees respectively. The Class II div 2 group had a slightly larger mean collum angle at 7.97 degrees. This however, was not statistically significant from the other groups.

Mandibular Canines

The Class I group had a mean of 7.66 degrees and the Class II div 1 group had a mean of 7.40 degrees. The Class III and the Class II div 2 group had a mean collum angle of 8.50 degrees and 8.75 degrees respectively. None of the different malocclusions were significantly different.

Overall, the mean collum angle values for only the Class II div 2 malocclusion were significantly different from the other malocclusions. In particular, it was only the maxillary central and maxillary lateral incisors of this group that showed a significant difference.

**Skeletal Classification Analysis**

A one-way analysis of variance was used to compare the collum angles of each tooth to each skeletal classification. The statistics were run with a 95% confidence interval and a p value of 0.05.

Table 4.3
*Mean Anterior Tooth Collum Angles per Skeletal Classification*

| Tooth | Molar Classsification | N | Mean Collum Angle in Degrees (Standard Deviation) |
|---|---|---|---|
| Upper Central | Class I | 303 | 3.71 (5.77) |
| | Class II div 1 | 185 | 4.41 (5.86) |
| | Class III | 101 | 3.87 (7.46) |
| | Class II div 2 | 21 | 8.91 (5.98) |
| | Total | 610 | 4.13 (6.17) |
| Upper Lateral | Class I | 278 | 6.08 (6.04) |
| | Class II div 1 | 173 | 6.41 6.34) |
| | Class III | 94 | 7.12 (7.74) |
| | Class II div 2 | 20 | 1.82 (7.15) |
| | Total | 565 | 6.20 (6.53) |
| Upper Canine | Class I | 245 | 1.78 (6.72) |
| | Class II div1 | 137 | 0.68 (6.53) |
| | Class III | 79 | -0.10 (7.37) |
| | Class II div 2 | 17 | 0.58 (7.31) |
| | Total | 478 | 1.11 (6.82) |
| Mandibular Central | Class I | 300 | 5.96 (3.81) |
| | Class II div 1 | 182 | 5.61 (3.41) |
| | Class III | 107 | 6.42 (3.79) |
| | Class II div 2 | 19 | 6.04 (4.42) |
| | Total | 608 | 5.94 (3.71) |
| Mandibular Lateral | Class I | 291 | 6.21 (4.23) |
| | Class II div 1 | 179 | 6.28 (4.57) |
| | Class III | 100 | 7.44 (4.16) |
| | Class II div 2 | 20 | 7.67 (3.43) |
| | Total | 590 | 6.49(4.32) |
| Mandibular Canine | Class I | 263 | 7.55 (4.74) |
| | Class II div 1 | 152 | 7.71 (4.16) |
| | Class III | 97 | 8.63 (5.44) |
| | Class II div 2 | 18 | 8.34 (4.81) |
| | Total | 530 | 7.82 (4.73) |

*These groups were significantly different at a p-value of 0.05.

Maxillary Central Incisors

The mean collum angle for a maxillary central incisor with a Class I skeletal pattern was 3.71 degrees. For the Class II div 1 and Class III skeletal patterns, the mean collum angles were 4.41 degrees and 3.87 degrees respectively. The Class II div 2 skeletal pattern was significantly different than all the other skeletal patterns with a mean collum angle of 8.91 degrees.

Maxillary Lateral Incisors

In the Class I skeletal pattern, the mean collum angle for a maxillary lateral incisor was 6.08 degrees. The Class II div 1 and III skeletal patterns had collum angles of 6.41 degrees and 7.12 degrees. The skeletal Class II div 2 skeletal pattern however, was 1.82 degrees. Therefore, the skeletal Class II div 2 pattern was significantly different from all other skeletal patterns.

Maxillary Canines

The Class I skeletal pattern had a mean collum angle of 1.78 degrees, the Class II div 1 skeletal pattern had a mean collum angle of 0.68 degrees, and the Class II div 2 skeletal pattern had a mean collum angle of 0.58 degrees. However, the Class III skeletal pattern had a negative mean collum angle of -0.10 degrees. Although it was negative, this was not statistically different from the other skeletal patterns.

Mandibular Central Incisors

The mandibular central incisors had a mean collum angle of 6.27 degrees for their skeletal Class I pattern. The Class III and Class II div 2 skeletal patterns had mean collum angles of 6.42 degrees and 6.04 degrees. The Class II div 1 skeletal pattern had the smallest mean collum angle at 5.61 degrees. This however, was not significantly different from the other skeletal patterns.

Mandibular Lateral Incisors

The mean collum angle for the mandibular lateral incisors for the Class I and Class II div 1 skeletal patterns were 6.21 degrees and 6.28 degrees respectively. For the Class III and Class II div 2 skeletal patterns, the mean collum angles were 7.44 degrees and 7.67 degrees. There was no significant difference among the four skeletal classifications.

Mandibular Canines

The mean collum angle for the Class I and Class II div 1 skeletal patterns were 7.55 degrees and 7.71 degrees respectively. The Class III and the Class II div 2 skeletal patterns had a mean collum angle of 8.63 degrees and 8.34 degrees. There was no statistical difference among the skeletal classifications for the mandibular canines.

**Difference Between Molar and Skeletal Classification Collum Angles**

Table 4.4
*Comparison of Means*

| Classification | N | Mean (Degrees) | Standard Deviation (Degrees) |
|---|---|---|---|
| Molar | 30 | 5.37 | 2.45 |
| Skeletal | 30 | 5.36 | 2.59 |

A mean comparison of the two classifications was completed. The overall mean for the molar classification was 5.37 degrees whereas, the overall mean for the skeletal classifications was 5.36 degrees. The results of this statistical analysis indicated that there was no significant difference between the two classifications. The significance level was tested at a p-level of 0.05.

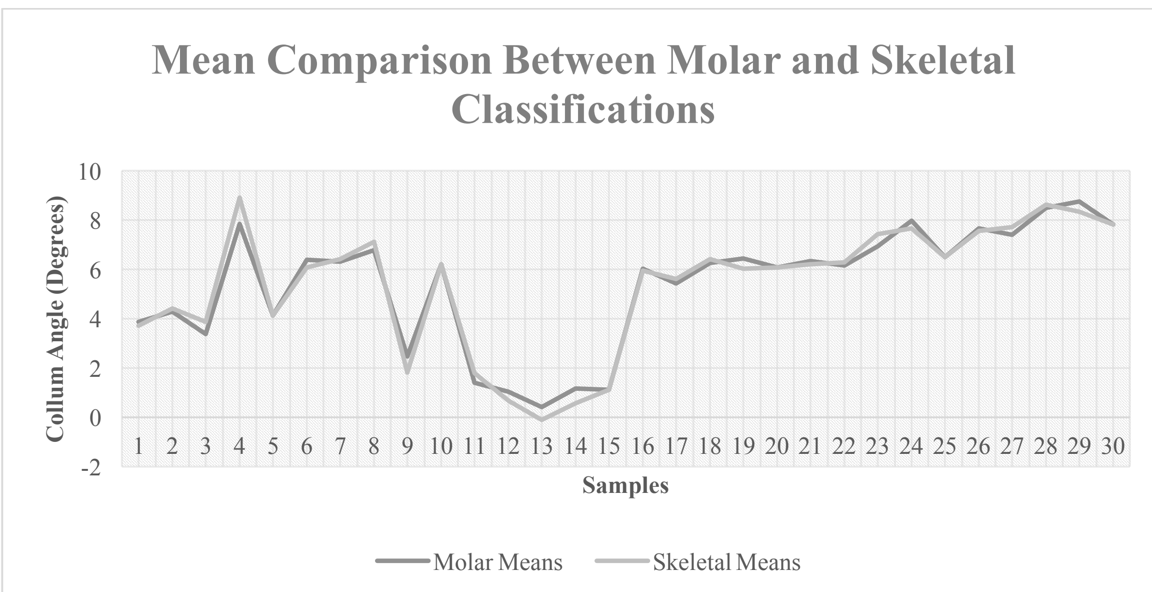


*Figure 4.2 Mean collum angle comparison between molar and skeletal classifications*

**Intra-observer Reliability**

Table 4.5
*Intraobserver Reliability*

| Tooth | Maxillary Central Incisor | Maxillary Lateral Incisor | Maxillary Canine | Mandibular Central Incisor | Mandibular Lateral Incisor | Mandibular Canine |
|---|---|---|---|---|---|---|
| $\kappa$ | 0.91 | 0.86 | 0.87 | 0.82 | 0.65 | 0.59 |

A paired samples t-test was conducted to determine intra-observer reliability. Kappa statistics were used to assess the percent agreement. The results of this test indicated that the maxillary central had a $\kappa$ value of 0.91. The maxillary lateral had a $\kappa$ value of 0.86 and the maxillary canine had a $\kappa$ value of 0.87. The mandibular centrals had a $\kappa$ value of 0.82 whereas the mandibular laterals and canines had a $\kappa$ value of 0.65 and 0.59 respectively. In evaluating the kappa statistics, the interpretation presented in "Practical Statistics for Medical Research" was used, (Altman, 1990). This meant that the measurements performed on the maxillary central incisors, maxillary lateral incisors, maxillary canines, and mandibular central incisors were in very good agreement. Subsequently, the measurements performed on the mandibular lateral incisors were in good agreement and the measurements performed on the mandibular canine were in moderate agreement.

# Chapter 5: Discussion

## The Collum Angle in Dentistry

In evaluating the collum angle, it is apparent that its consequences may have several applications in dentistry. This is especially important in the anterior teeth where esthetics is a major concern. In regards to restorative dentistry, post placement in teeth with large collum angles may cause difficulty in constructing the core. The post may be shortened in order to restore the crown with the proper inclination. In this way, the retention of the final restoration is reduced. In regards to periodontics, root prominence, dehiscences, and soft tissue esthetics may be affected. This is especially apparent in teeth with negative collum angles, where the root is facially inclined in relation to the crown axis. When placing anterior implants, the implant post is commonly placed parallel to the longitudinal axis of the previous root. However, if the previous tooth had a large collum angle, the crown must be restored as such to prevent misalignment of the restoration. This necessitates the use of an angled abutment. However, when such an abutment is used, stress is concentrated on the buccal side off the fixture, causing post-surgical tension in the gingiva (Shen, 2012). This may therefore, cause recession and other unwarranted cosmetic defects. Persistence of this post-surgical tension may even be problematic when a soft tissue graft is completed, causing the recession to return. In addition, increased abutment angulations have been shown to increase the magnitude of stress and strain in cortical bone (Clelland, 1995). This increase in stress generation is also seen in orthodontics with large collum angles in natural dentition. In Heravi's et al's study, retraction of Class II div 2 maxillary central incisors resulted in forces that were 1.18x higher than in the Class I maxillary incisors. However, when an intrusive force was applied, the teeth with larger collum angles demonstrated lower stress distribution to the periodontal ligament, (Heravi, 2013). Although the collum angle may have various effects in dentistry, its application has been most frequently discussed in regards to orthodontics.

**The Collum Angle in Orthodontics**

When Dr. Lawrence Andrews designed the first fully programmable brackets, he revolutionized the field of orthodontics. This development was based on the Six Keys of Normal Occlusion, in which he named crown inclination as the third key (Andrews, 1972). Although the importance of crown inclination was widely discussed, no mention of the crown in relation to the root was made in the "Six Keys of Normal Occlusion" (Andrews, 1972). This omission may have subsequently, propagated the assumption that the longitudinal axis of the crown and root formed a straight line (Harris, 1993). The aforementioned concept is especially apparent in cephalometric analyses where the crown to root angulation is not evident in the maxillary incisor templates (Bryant, 1984). Instead, the maxillary incisor template is automatically drawn in, such that the long axis of the crown and root are identical. By doing so, crown inclination is taken into consideration but no forethought is given to the inclination of the root and its inherent consequences.

Although Andrews disregarded root inclination when developing the Straight Wire Appliance, the importance of root position is evident in the grading system developed by the American Board of Orthodontics (ABO). As the golden standard of orthodontics, the ABO has carefully selected root position as a paradigm in which Board Certified cases are graded upon. In assessing root position as a fundamental criterion, the ABO has noted its value in the treatment planning of cases.

To assess crown to root angulation, the collum angle was used in this study. The actual crown to root angulation was measured by quantifying the angulation between the longitudinal axis of the crown and the longitudinal axis of the root. This angle was then converted to its supplementary angle, by subtracting its value from 180 degrees. Instead of using large values that were difficult to comprehend, the collum angle was chosen for its ease in directional analysis of crown inclination. This was due to the fact that the angular measurements were based on the value of zero rather than the alternative of 180 degrees. In this way, a positive value would easily define the angular measurement in the lingual direction and a negative value would indicate a labial direction of crown bending. Because of this, the crown to root inclination was measured as the collum angle, rather than the crown to root angulation.

With the use of CBCT, this study was the first to quantify the collum angles of all anterior teeth. Unlike previous studies, superimposition issues with lateral cephalograms were overcome to allow for measurements of teeth adjacent to the maxillary central incisors. In addition, large numbers of extracted teeth were not necessary to measure the collum angle. This allowed for quantification of a large volume of teeth which may have been otherwise difficult to obtain. Furthermore, the 3D rendering capabilities of CBCT technology allowed for correct three-dimensional orientation of each tooth. This is especially important in this study because the level of the CEJ changes as you shift away from the center of the tooth. Thus, if the slice used for measurement is not properly oriented, the level of the CEJ will change. This method of orientation was not possible in the lateral cephalograms used in this past. In this way, the use of CBCT technology improved the accuracy and the scope in which the measurements were made.

**Differentiation of the Collum Angle from Zero Degrees**

In this study, the results of a one sample t-test demonstrated that the mean collum angles for all anterior teeth were significantly different from zero. The mean collum angle for the central incisor was 4.13 degrees while collum angles of the maxillary lateral, mandibular central and mandibular lateral incisors were relatively similar at 6.20 degrees, 5.94 degrees and 6.49 degrees respectively. Notably, it was found that the mandibular canine exhibited the largest collum angle whereas the maxillary canine demonstrated the smallest collum angle. This was similar to Germane et al.'s study in which the maxillary canines had a more facially inclined root and the mandibular canines had a comparatively lingually inclined root (Germane, 1986). However, Germane's study found a more facially inclined mean for all maxillary canines at -2.46 degrees in comparison to our mean of 1.11 degrees. For the mandibular canines, our mean collum angle was 7.82 whereas, Germane et al. reported the mean as 4.83 degrees. Since the maxillary canine exhibited the smallest collum angle of all the anterior teeth, the relative root position was found to be further facial than the rest of the anterior teeth. This facial positioning of the maxillary canine root may theoretically affect torque considerations.

In Andrews' torque prescription, negative maxillary canine torque is programmed into the bracket. With the small collum angle anatomically inherent in the maxillary canines, the result is that the effective torque is increased (Germane, 1986). On the contrary, when positive maxillary canine torque is prescribed in a bracket, the effective torque decreases. This can be seen in the prescription for a bioprogressive appliance (Germane, 1986). In effect, torque expression has varying effects on root position when variations in crown to root angulation are present. Consequently, variation in the collum angle can affect cuspid root prominence during treatment.

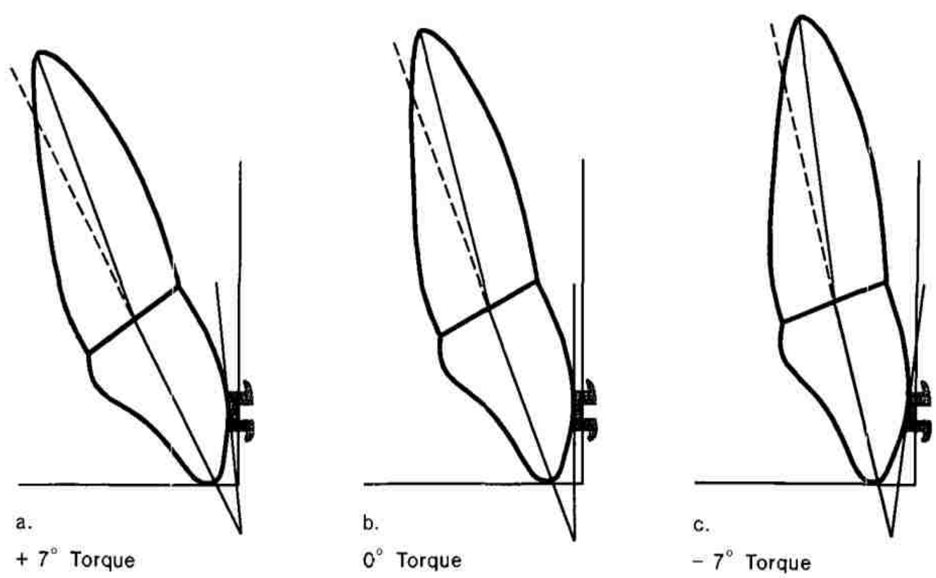


*Figure 5.1 Root positions at various torque prescriptions. Adapted from "The relationship of canines in relation to the preadjusted appliance" by Germane et al.*

When the collum angle is significantly deviated from zero, the cortical plate is more likely to be contacted by the root, causing unwarranted root resorption. In severe cases, the development of a dehiscence and alveolar perforation are risk factors (Delivanis, 1980). Furthermore, it has been found that when retraction forces were placed on teeth with varying collum angles, stress generated in the periodontal ligament are larger in those with larger collum angles (Heravi, 2013). It is important to note that in regards to the cortical plate, extrusive and intrusive mechanics may be limited, along with the extent in which anterior teeth can be torqued (Harris, 1993).

In addition to its effects on tooth movement, torque in the Straight Wire Appliance can play a role in anchorage. When the roots of anterior teeth are torqued so that the roots contact the lingual cortical plate, tooth movement is slowed due to the density of the cortical plate. This is termed cortical anchorage (Profitt et al., 2013). In extraction cases when the anterior teeth are torqued into the cortical plate, the resulting anterior torqueing couples move the posterior teeth forward, changing the anchorage requirements (Meyer and Nelson, 1978). Despite being an established form of anchorage control, it is pertinent to understand that this method of anchorage control may predispose the anterior teeth to the negative effects of root resorption as previously discussed. Since the mean collum angles were found to be significantly different from zero, it can be erroneous to disregard the crown to root angulation as it has the potential to impede treatment mechanics. Therefore, it would be wise for a clinician to consider the consequences of the collum angle in the course of treatment.

**The Collum Angle and Molar Classification**

In analyzing the collum angles of the anterior teeth between molar classifications, it was found that only the maxillary centrals and laterals had significant differences between molar relationships. In particular, the maxillary central incisors had significant differences between all molar classifications and the Class II div 2 group. The mean value for the Class II div 2 group was 7.86 degrees whereas the individual mean for the Class I, Class II and Class III maxillary central incisors were 3.88 degrees, 4.30 degrees and 3.39 degrees. This suggests that a significantly larger collum angle is present in Class II div 2 malocclusions. The larger collum angles in the maxillary central incisors theoretically coincide with the retroclined maxillary central incisors unique to this malocclusion. Since only the Class II div 2 malocclusion was defined by the axial bending of the maxillary central incisors, the retroclination of the incisors provide a plausible explanation for the larger collum angles found in this malocclusion.

Similarly, the maxillary lateral incisors showed an analogous comparison with regard to the pattern of results. All molar classifications demonstrated a significant difference when compared to the Class II div 2 malocclusions. However, the mean collum angle for the lateral incisors in the Class II div 2 malocclusion was 2.47 degrees whereas the Class I, Class II and Class III malocclusions had mean collum angles of 6.38 degrees, 6.32 degrees and 6.78 degrees, respectively. This data suggests that the Class II div 2 malocclusions had a smaller mean collum angle when compared to the other malocclusions. In regards to the Class II div 2 malocclusion, the clinical implication of a smaller collum angle represents the tendency of the malocclusion to have flared incisors.

The lateral incisors in this data set were found to have a more labial inclination than that of the corresponding maxillary central incisors, which were expected to be retroclined in this malocclusion. In this way, the mean collum angles of the maxillary central and lateral incisors corroborate with the traditional characteristics of Class II div 2 malocclusions.

A classical Class II div 2 malocclusion consists of an end on Class II molar relationship, retroclined maxillary incisors, proclined laterals, and a deep overbite. Other features include a low mandibular plane angle and a high lower lip line. Although there are several varying characteristics defining a Class II div 2 malocclusion, the retroclined maxillary incisors and the flared lateral incisors are typically known as its classical presentation. This palatal "bending" of the maxillary central incisors was first characterized by Andreasen with the use of the longitudinal axes of the crown and the root. Andreasen stated that if the collum angle of a maxillary central incisor was abnormally large, it would potentially give rise to a deep overbite (Andreasen, 1930). Similarly, Andrews stated that a proper interincisal angle between maxillary and mandibular anterior teeth would mitigate the overeruption of lower incisors and the subsequent formation of a deep bite (Andrews, 1972). Thirdly, Backlund stated that the lingually tipped crown of the maxillary central incisor was a major factor in the development of a deep bite in Class II div 2 patients (Backlund, 1960). He stated that when a large interincisal angle exists, a "gliding contact" is present. This decreases the axial stress on teeth which subsequently, contributes to a marked overbite (Delanivis, 1980). In our study, the Class II div 2 malocclusion had the largest statistically significant collum angles for the maxillary central incisors. Because of this, it is ostensible that the theories regarding the development of the deep bite seen in the Class II div 2 malocclusion are supported by the large collum angles found in maxillary central incisors of this study.

Several other theories have been postulated regarding the development of the Class II div 2 malocclusion (Delivanis,1980). This includes both hereditary and environmental factors. According to Logan et al., the irregular inclination of the maxillary central incisors responsible for a deep bite is genetically determined (Logan, 1959). It has also been suggested that the shape and size of crowns are under genetic control whereas root form is controlled by environmental factors (Harris, 1993). In the development of the permanent dentition, the mandibular permanent teeth usually erupt earlier than the opposing maxillary teeth. Because of this, the overjet and overbite of a developing occlusion are dictated by the position of the lower incisors. Proper eruption guidance of the incisors is then dictated by tongue pressure lingually and lip pressure facially. If the pressures are unbalanced during the eruption of teeth, the lower lip pressure causes bending of the tooth at the CEJ. As such, Harris suggests that collum angles closer to zero are found in occlusions where a normal overjet relationship exists. Therefore, large collum angles found in retroclined maxillary central incisors are thought to be due to non-physiologic lip pressure exerted on the maxillary and mandibular incisors.

In Srinivasan's study, they found that the magnitude of the collum angle was dependent on the position of the lower lip line in relation to the maxillary central incisor.

They found that when the lower lip was touching the middle third, the mean collum angle was increased. Alternately, when the lower lip was located in the cervical third of the maxillary incisor, the collum angle became more negative. This indicates that when the lower lip is positioned in the cervical third, the maxillary central incisor receives pressure in the cervical portion, labially bending the tooth. When the lower lip was located on the incisal third or without contact with the maxillary incisor, the collum angles were found to be very small. This finding further confirms the significance of the lower lip on the development of the collum angle. Following the same reasoning, the flaring of the lateral incisors can be explained by the fact that they are cervically positioned in comparison to the maxillary central incisors. This would theoretically position the lip closer to the incisal third of the lateral incisor, decreasing the bending effect of the lower lip. These theoretical proposals follow Moss's Functional Theory of Growth which proclaims that the soft tissue determines the growth of hard tissues (Moss, 1969). Therefore, the large collum angles found in the maxillary central incisors of Class II div 2 malocclusions can be potentially explained by the enhanced lip pressure disrupting the eruptive path of the maxillary central incisors. Using the same rationale, the significantly smaller collum angles seen in the Class II div 2 maxillary lateral incisors can be rationalized. By being anatomically positioned more cervical than the centrals, the lower lip pressure is no longer focused on the middle third. Instead the lip pressure is located on the incisal third or without any contact at all. The effect of this relocation of pressure is that a smaller collum angle is theoretically produced.

Although there was a significant difference between all molar occlusions and the Class II div 2 group, no other significance between molar classifications were found amongst all the teeth. This is in disagreement with Harris's study, in which he found a significant difference between the Class III malocclusion and the other malocclusions. In his study, the Class III malocclusions had a significantly larger collum angle than both Class I and Class II malocclusions (Harris, 1993). He reasoned that this finding was due to the crowns of the maxillary incisors being constrained within the mandibular dental arch, a phenotype commonly seen in Class III malocclusions. Because the maxillary central incisor crowns erupt after the mandibular arch, the eruption path of the maxillary central incisors are deflected lingually. Therefore, the mandibular arcade's interference of maxillary central incisor eruption is responsible for the large collum angles seen in Class III malocclusions.

A reason in which a significant difference was not seen in our study, may be due to the fact that we did not differentiate Class III malocclusions based on their severity. A Class III molar occlusion can include those with dental compensation and those in which a complete anterior crossbite is present. It is possible that in Harris' study, only severe Class III cases where dental compensation was not possible were used in the sample. This would alter the results since the mandibular arcade would theoretically deflect the maxillary incisor crowns lingually. However, if there were Class III cases with dental compensation, the maxillary central incisors would be flared labially, significantly altering the mean collum angle. Since our study did not differentiate the different types of Class III molar occlusion, the results may have negated any significant difference that may have been found in the varying Class III malocclusions. In addition, the sample size used in Harris' study was considerably smaller with only 21 samples in the Class III malocclusion.

Despite finding different results from Harris, our experimental outcome was in agreement with the research conducted by Delivanis, Bryant, Williams, Srinivasan and Shen. Unlike Harris' study, which did not separate the divisions of Class II malocclusions, the aforementioned studies included the Class II div 2 malocclusion as a distinct group. These studies showed that a significant difference was seen only in the Class II div 2 malocclusions when compared to the other malocclusions. This difference was shown anatomically in Mcintyre's study. It was found that the shape of Class II div 2 maxillary central incisors were significantly different from the other malocclusions. In comparison, they had greater axial bending, shorter roots, longer crowns and reduced labiopalatal thickness (Mcintyre, 2003). These anatomical properties were found to have contributed to the development of the malocclusion. Specifically, he states that the poorly developed cingulae, retroclined crowns and the reduced labiopalatal thickness of the incisors contribute to the increased interincisal angle responsible for the development of a deep bite. Although Mctintyre confirms the anatomical correlation of the large collum angles in Class II div 2 malocclusions, his proposed rationale contradicts that of Harris. It is acknowledged that during root formation, it is possible that the crown to root angulation can be changed. However, he states that during eruption, 2/3s of the root has already been mineralized and therefore, its influence on root formation would only alter the apical ⅓. Because of this, he suggests that dilacerations of the apical third instead of axial bending occurs. Although this was proposed, he found that 63% of the Class II div 2 maxillary incisors were found to have axial bending at the cementoenamel junction. This suggests that the etiology of the axial bending seen in Class II div 2 maxillary central incisors may be hereditary. Regardless of the genetic or environmental etiology of the collum angle, emphasis should be placed on the fact that pronounced collum angles continue to alter the interincisal angle and the relationship between the mandibular central incisor tip and the maxillary incisor centroid. In this way, the maxillary central incisor collum angles are fundamental in the development of the deep bite seen in Class II div 2 malocclusions.

As mentioned before, these studies emphasized the importance of the significantly larger collum angle in Class II div 2 malocclusions during treatment mechanics. When the collum angle is large, issues with the root impingement on the cortical plates are a concern. This may cause problems with unwarranted root resorption and biomechanical torquing during orthodontic treatment. In addition, it has been found that when a retraction force is applied to teeth with larger collum angles, the force transferred to the periodontal ligament is larger (Heravi, 2013). Because of these various factors, it is apparent that the collum angle should be taken into consideration throughout the treatment of orthodontics. In particular, greater attention may be warranted in patients with Class II div 2 malocclusions.

**The Collum Angle and Skeletal Classification**

Since the molar classification sample was defined solely by Angle's molar classification, each side of a patient was considered a different sample. Theoretically, this may induce several confounding factors into the study. In order to evaluate the internal validity of the study, a second category was used to test if the collum angles would differ if samples from the same patient were classified in the same way. This would ideally eliminate the confounding variables that may appear in the molar classification sample when each side of a single patient was categorized into a different category. As such, the patients were separated by skeletal classifications.

Analogous to the results from the molar classification sample, the only significant differences within the skeletal classifications were found between the maxillary central and lateral incisors. When compared to all the other skeletal classifications, only the Class II div 2 category was significantly different from the other skeletal classifications.

A comparison of means was used to see if there were any significant differences between the mean collum angles of the molar and skeletal classifications for each anterior tooth. This test showed that there were no significant differences between the two categories at a p-level of 0.05. From this, we can infer that the confounding factors that may have limited the molar classification sample were negligible.

**Limitations**

One of the major limitations in this study was that a Class I normal occlusion group was not included in this study. Such a group would serve as a control in which all malocclusions could be compared. However, since records were extracted from the Department of Orthodontics and Dentofacial Orthopedics at the University of Nevada, Las Vegas, Class I normal occlusions were not available. This is because patients with normal occlusions do not typically seek orthodontic treatment.

A second limitation to this study was the presence of artifacts on CBCT scans. Although most of the scans that had poor radiographic quality were screened out, there were scans included in the study where noise posed some issues. The "graining" effect on an image appears when the projection of images presents inconsistent attenuation values (Kincade, 2011). While radiation is scattered, it is produced in various directions and the detector records this in the form of pixels. Unlike the attenuation of x-ray beams with a specific path, the non-linear attenuation is recorded by an area detector as noise (Schulze 2011). This causes image degradation and reduces the human ability to accurately distinguish the points being measured. For example, in a single scan, noise can be apparent in different areas of the scan. The maxillary central incisor root apex may be clearly discernible, however, when the slice for the mandibular incisor is created, the root apex may be significantly less apparent. This graining effect was not uniform throughout the scans, causing room for error in the measurements. These measurement errors are then compounded with the accuracy specifications of the angular measurement tool built into Anatomage's software of +/-1.5 degrees.

Another issue with measurement may stem from wear of the incisal edges. Although noticeably worn teeth were excluded from this study, the majority of the adult dentition has experienced some extent of wear. A solution to this would be to only measure patients in which mamelons were still present. However, large samples of adult dentition with mamelons present are generally not feasible. Because of this, we have considered the wear in our samples negligible.

Additionally, our sample size for the Class II div 2 malocclusions was comparatively small. With a total sample size of 652, only 70 of the samples were part of the Class II div 2 molar malocclusion.  For the skeletal classifications, only 42 samples were obtained for the Class II div 2 group. Even within these samples, not all teeth were able to be measured, further reducing the sample size. Thus, the sample size for the Class II div 2 group was significantly smaller in comparison to the other classifications.

Another limitation in our study was that the patients were not differentiated by ethnicity. Because the sample used had a primarily Hispanic and Caucasian demographic, the collum angles may have been skewed towards these ethnic norms. Differences in ethnic norms have also been indicated in other papers. For example, Asian races have been noted to have larger collum angles due to their ethnic propensity towards bimaxillary protrusion (Shen, 2012). Because we did not differentiate our samples by ethnicity, certain ethnic norms may have skewed the mean collum angles found in this study.

Last but not least, the method of sampling may have introduced confounding factors. For the skeletal classifications, the Class I, Class II div 1 and Class III classifications themselves were taken as noted in the patient charts. The Class II div 2 skeletal classifications were reaffirmed with our specifications noted in the methodology. This however, may be problematic since different residents were responsible for entering the classifications in the chart. For the molar classifications, each side of a patient's mouth was used as a separate sample. By using the same patient as two different samples, extraneous variables that could otherwise affect the results could be introduced. However, an attempt to address this issue was done by comparing the results with those found in the skeletal classifications. The skeletal classifications were organized such that both sides of a single patient were grouped identically.

**Future Research**

Although the collum angle has been evaluated in literature, studies pertaining to its development have not been investigated. Currently, two theories concerning its development are based on hereditary elements or unbalanced forces during eruption that may deflect the crown. Because of this, a new study is warranted in order to determine whether the "bending" of the crown is due to environmental or genetic factors.

Additionally, other studies may be conducted to confirm if the incisal wear in an adult population is indeed negligible. This can be done by perhaps using the tip of the dentin crest of the dentoenamel junction instead of the incisor superioris. By using this point to evaluate the crown inclination, the longitudinal axis is not altered by external factors involving the enamel such as wear and attrition.

Thirdly, another study may be conducted in which the Class III malocclusions were further categorized into different groups. The Class III malocclusions can be separated into those with a complete anterior crossbite and those with dental compensation. By doing so, the investigators may be able to distinguish if the collum angles are affected by the deflection of the mandibular arcade. When such groups are identified, the mean collum angles of the Class III malocclusion group may not be diluted into an average collum angle that may have appeared in this study.

**Conclusions**

This study concluded that:

1. The mean Collum angle for all anterior teeth were significantly different from zero. The mean collum angle for the maxillary central incisor was found to be 4.13 degrees. In addition, the mean collum angle for the maxillary lateral incisor was 6.20 degrees and the mean collum angle for the maxillary canine was 1.11 degrees. For the mandibular teeth, the mean collum angle for the mandibular central incisor was 5.94 degrees. Similarly, the mean collum angle for the mandibular lateral incisors and mandibular canines were 6.49 degrees and 7.82 degrees, respectively. It was interesting to note, that the maxillary canine collum angle had the smallest collum angle, while the mandibular canine had the largest collum angle of all anterior teeth.

2. When comparing the collum angles in different molar classifications, only the maxillary central and lateral incisors were significantly different. In examining these teeth, the Class II div 2 malocclusion was significantly different from all of the other malocclusions. The Class II div 2 maxillary central incisors had a significantly larger collum angle in comparison to the other maxillary incisors, with a mean of 7.86 degrees. Conversely, the maxillary lateral incisors had a significantly smaller collum angle than the other lateral incisors, with a mean of 2.47 degrees. These results coincided with the classical appearance of a Class II div 2 malocclusion in which the maxillary centrals are retroclined and the laterals are flared.

3. When comparing the mean collum angles of the skeletal classifications, the results were almost identical to those of the molar classifications. In effect, the corroborating results resolved any questions that may have arose regarding the confounding variables that may have been implicit in the methodology.

4. When the collum angle is significantly larger than zero, treatment mechanics can be affected. In particular, torquing of such teeth against the cortical plate may be limited in order to avoid unwarranted root resorption and alveolar perforation. Extrusive and intrusive mechanics may also be limited during orthodontic treatment. In Class II div 2 maxillary central incisors, the large collum angle may be a contributing factor in the development of the deep bite.

Appendix A

## UNLV Biomedical IRB - Administrative Review
## Notice of Excluded Activity

| | |
|---|---|
| **DATE:** | December 10, 2015 |
| **TO:** | James Mah, DDS, MSc, DMSc |
| **FROM:** | UNLV Biomedical IRB |
| **PROTOCOL TITLE:** | [844006-1] Differential CBCT Analysis of Collum Angles in Maxillary and Mandibular Anterior Teeth In Patients with Different Malocclusions |
| **SUBMISSION TYPE:** | New Project |
| **ACTION:** | EXCLUDED - NOT HUMAN SUBJECTS RESEARCH |
| **REVIEW DATE:** | December 10, 2015 |
| **REVIEW TYPE:** | Administrative Review |

Thank you for your submission of New Project materials for this protocol. This memorandum is notification that the protocol referenced above has been reviewed as indicated in Federal regulatory statutes 45CFR46.

The UNLV Biomedical IRB has determined this protocol does not meet the definition of human subjects research under the purview of the IRB according to federal regulations. It is not in need of further review or approval by the IRB.

We will retain a copy of this correspondence with our records.

*Any* changes to the excluded activity may cause this protocol to require a different level of IRB review. Should any changes need to be made, please submit a Modification Form.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

Office of Research Integrity - Human Subjects
4505 Maryland Parkway . Box 451047 . Las Vegas, Nevada 89154-1047
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Curriculum Vitae

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## EDUCATION

2016 Anticipated M.S. Oral Biology, University of Nevada, Las Vegas

2016 Anticipated Certificate, Advanced Education in Orthodontics and Dentofacial Orthopedics, University of Nevada, Las Vegas

2014 DMD, Nova Southeastern University, Fort Lauderdale, Florida

2010 B.S. Double major in Biological and Physical Sciences, University of Alberta, Edmonton, Alberta

## AWARDS

2016 ***UNLV Postgraduate Student Research Award***

University of Nevada, Las Vegas School of Dental Medicine. Las Vegas, Nevada.

2014 ***Nova Southeastern University Oral Medicine Award***

Nova Southeastern University. Fort Lauderdale, Florida.

2010 ***Golden Key International Honor Society Scholar***

Golden Key International Honor Society, University of Alberta Edmonton, Alberta.

2009 ***University of Alberta Alumni Advantage Scholarship***

University of Alberta, Edmonton, Alberta.

2009 ***TD Insurance Meloche Monnex Leadership Award***

TD Ameritrade Bank/University of Alberta, Edmonton, Alberta.

2007 ***University of Alberta Academic Excellence***

University of Alberta, Edmonton, Alberta.

2007 ***Faculty of Science Academic Excellence Scholarship***

University of Alberta, Edmonton, Alberta.