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Three-dimensional Analysis of the Impacted Maxillary Canine: Localization and Assessment of Severity

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Masters of Dental Science

Three-Dimensional Analysis of the Impacted Maxillary Canine: Localization and Assessment of Severity

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Abstract

Aims & Objectives: The objective of this study is to determine the location of impacted or unerupted maxillary canines and evaluate their position and severity as they correlate to the clinical aspect of orthodontics. In addition, we propose to identify specific regions in the maxilla where impacted canines are more common, and to evaluate these methods for reliability and accuracy. Finally, we intend to introduce a 3-D classification for maxillary impacted canines.

Materials & Methods: We reviewed approximately 1000 CBCT images of patients with impacted maxillary canines. From these images, 207 CBCT's, with 314 unerupted canines were selected to be evaluated to determine the specific location, angulation and severity. The canine was classified as unerupted or impacted based on our definition of an impacted canine: when root development was complete or the contralateral canine was fully erupted. Of the 314 unerupted canines, 174 were classified as impacted. Our methods were analyzed for reliability and accuracy.

Results & Discussion: Excellent inter-examiner and intra-examiner reliability for all variables except axial deviations from the midline, which exhibited good inter-examiner reliability, was observed. Measurements compared using a digital caliper and those acquired from a CBCT image on a typodont showed very high similarity. Females were reported to be affected 1.63 times more frequently than males. This frequency increased to a ratio of 1.93:1 once a canine was defined as impacted. Palatally displaced canines were observed at a rate of 38.54% compared to 40.76% for buccal displacement and 20.70% of the canines were located midalveolar. However, once a canine was defined as impacted, palatal displacement was 2.14 times more likely than a buccal position. From a coronal view, 34.08% of canines were normally positioned, 62.10% were found to be located mesial to the distal border of the lateral incisor and 45.54% were located mesial to the midline of the lateral incisor. Impacted canines had a higher percentage classified in these regions, with 78.16% located mesial to the distal border of the lateral incisor and 60.92% mesial to the midline of the lateral incisor. Canines were mesially tipped in 59.24% of the cases. However, when diagnosed as impacted 78.29% of canines were mesially angulated. Of the canines 33.44% were identified as mild, 37.58% moderate, and 28.98% severe. Additionally, as the age of a patient increased, severity was found to significantly increase. With each yearly increase in age, the chance of having a severe impaction increased by 3.2%.

Conclusion: The location of all 314 impacted or unerupted maxillary canines was evaluated by position, angulation and severity as they correlate to the clinical aspect of orthodontics. Specific regions on the maxilla were identified in which impacted canines were more commonly located. Once diagnosed as

impacted, females were observed to be affected 1.93 times more frequently than males. Impacted canines were palatally positioned 2.14 times more commonly than buccal displacement. From a frontal perspective, impacted canines were located mesial to the distal border of the lateral incisor in 78.16% of cases and 60.92% were located mesial to the midline of the lateral incisor. As the age of a patient increased, the chance of having a severe impaction increased by 3.2%. The methods outlined were found to be reliable and accurate. In addition, a classification for impacted maxillary canines examined by CBCT imaging was introduced.

Introduction

Impacted maxillary canines are a commonly encountered problem in Orthodontics. Other than third molars, maxillary canines are the most frequently impacted teeth, occurring in 1% to 3% of the population. (1) (2) (3) As described by Moyers et al (5);"The maxillary cuspid follows a more difficult and tortuous path of eruption than any other tooth." The etiology of these types of impactions has been attributed to one of two theories; the guidance theory and the genetic theory. The guidance theory proposes that the lateral incisor root serves as a guide for the eruption of the canine. The canine lacks guidance during the eruption pathway due to a hypoplastic or missing lateral incisor. (6) This theory is supported by the fact that palatally displaced canines are frequently found in dentitions with peg-shaped or missing laterals. (7) (8) The genetic theory states that genetic factors are the primary origin of palatally displaced maxillary canines. (4) Research has noted a high correlation of other dental anomalies occurring along with the palatally displaced canine. Becker et al. (9) showed 47.7% of palatally displaced canines had anomalous adjacent lateral incisors. Becker also showed a 2.4x increase in impacted canines adjacent to missing laterals. This could be due to the local environment or genetic factors, which supports both theories. Other studies have also illustrated a familial link between maxillary canine impactions. (10) However, the exact etiology of an impacted canine still remains uncertain.

Radiographic evaluation is a critical component of the diagnoses of an impacted canine. It is the most commonly utilized diagnostic tool for such occurrences. (4) Traditionally, intraoral and extraoral radiographs have been used to pinpoint the location of an unerupted canine. One method utilizes an occlusal film along with a panoramic x-ray, while another uses multiple peri-

apical images to locate the impaction.[1][4] Although these tools have aided us in the past, new technology has been shown to be more accurate in determining the location of impactions as well as the extent of resorption caused by the condition. Two-dimensional imaging has many well documented limitations, including magnification, geometric distortion, superimpositions, and elongation and foreshortening of objects.[20][21] In contrast, 3-D imaging has come to the forefront in the diagnosis and treatment planning of "the anatomical truth."[22] Numerous studies have exemplified the diagnostic advantage of 3-D imaging over traditional methods of 2-D imaging. Boticelli et al.[21], showed significant differences between 2-D and 3-D imaging when determining the location of an unerupted canine. This was attributed to distortion, magnification, and the superimposition of anatomic structures that commonly occurs in the two-dimensional images. Wreidt et al.[23] showed that with panoramic x-rays, resorptions were overlooked in 20% of the patients evaluated, and the canine was located properly in only 64% of patients. In a study by Alqerban et al.[24], two-dimensional and three-dimensional images were taken on a cadaver skull with an impacted canine. Root resorption was detected 90-91% of the time compared with 70% when using CBCT (Cone beam computed tomography) vs. panoramic imaging.[24] Ericson and Kurol in 1987[25] demonstrated that 1/3 of the resorbed teeth in their study had a normal appearance on the peri-apical film. They attributed this to the fact that buccal and lingual resorptions occur in 50% of the cases, and a midroot lesion is common.[18][25] Resorption occurring in these regions may be undetectable using two-dimensional radiographs. The above mentioned studies substantiate the advantages of 3-D imaging in regards to impacted canines.

There are several clinical signs that indicate the possibility of a canine impaction. Delayed eruption of the canine, prolonged retention of the deciduous canine, absence of a normal labial bulge, presence of a palatal bulge, and delayed eruption, tipping, or migration of the lateral incisor may be clinical findings that signify impaction.[1] The presence of an impacted canine may cause no harmful effects, however numerous consequences have been associated with this anomaly. If left untreated, the migration of adjacent teeth, loss of arch length, and most significantly, resorption of neighboring teeth may occur.[1][4] Resorption of adjacent teeth has been observed 40.5% to 48% of the time, with even 77.8% being reported in some studies.[11][12][13] Identifying the precise location of an impacted maxillary canine can be an essential part of both diagnosis and treatment planning. According to Bedoya et al.[4], "Assessing the position of

the impacted canine is key to determining the feasibility of and proper access for a surgical procedure, as well as the best direction for application of orthodontics forces." Without proper diagnosis, the direction of forces as well as the method of surgical exposure may be incorrectly determined. Various diagnostic aids can analyze the numerous factors that may lead to a canine becoming impacted. Radiographically, position and angulation have been shown to accurately predict the likelihood of a canine becoming impacted. Studies have demonstrated that in 78% to 82% of canines destined to be impacted, the cusp tip crossed the distal aspect of the lateral incisor root. [(14) (15)] Sajnani and King [(16)] illustrated the importance of angulation as a tool for predicting whether a cuspid is destined to be impacted. Their findings show that after age 9, the horizontal angulation increases 20° to 40° in relation to the midline compared to a normally erupting canine.

Locating an impacted canine may also aid in distinguishing the possibility of causing damage to adjacent structures. Resorption of the maxillary incisors has been shown to occur in 48% of cases with ectopic erupting maxillary canines. As the canine cusp tip is positioned more mesially, a higher rate of resorption was observed. [(11)(18)(41)] A study using CT (Computed tomography) imaging demonstrated that resorption is mainly caused by contact and physiological pressure from the ectopic canine. [(12)] Resorption occurred 94.3% of the time when the impacted canine was in close contact with the incisors. [(11)] Angulation may also be a factor in determining whether an ectopic canine will cause resorption to adjacent teeth. The risk of resorption increases by 50% when the inclination relative to the midline exceeds 25° from the frontal view. [(18)] In addition, they found that impacted canines that caused resorption had an increase in horizontal angulation of 18.1° from an occlusal perspective compared to normally erupting canines. The identification of root resorption may lead to modifications in treatment planning, such as extracting a resorbed lateral incisor over a premolar in an extraction case. [(19)]

The precise location of an impacted canine has a direct effect on the management and treatment of the abnormality. In many cases, it can be beneficial to extract the deciduous canine as an interceptive treatment allowing the impacted canine to erupt. Early extraction of a deciduous canine when the succeeding tooth is impacted resulted in normalization of eruption in 78% of cases. [(17)] However, this result was significantly different when the canine was positioned mesial to the midline of the permanent lateral incisor. In fact, a normal eruption pattern was seen in 91% of the cases when the canine was distal to this midline, compared to 64% when it was

positioned mesial. [17] Angulation also plays a role in extracting deciduous canines to increase the chance of normal eruption of the impacted canine. As the horizontal angulation of the canine increases compared to the midline, the probability of successful eruption decreases. [26] When the angulation exceeds 31 degrees relative to the midline, the chance of normal eruption after extraction decreased significantly. [26]

In the absence of prevention, surgical and orthodontic treatment should be considered in order to bring the ectopic tooth into occlusion. (4) As stated by Bishara [1], "The diagnosis and treatment of this problem usually requires the expertise and cooperation of the general practitioner, the pediatric dentist, the oral surgeon, and the periodontist, as well as the orthodontist." From a surgical perspective, localization of the impacted canine aids in establishing the method utilized to uncover the tooth. If the inappropriate surgical technique is selected by the surgeon, the esthetic result may be unpredictable. [27] It may also lead to a more difficult and time consuming task for the orthodontist in aligning the impacted tooth within the maxillary arch. [27] The surgical method chosen depends on whether the canine is located in a labial or palatal position. It has also been proven that periodontal conditions of the impacted canine and adjacent teeth after surgical and orthodontic treatment are dependent on the initial vertical and horizontal position of the canine. [28] With this in mind, Kokich established four criteria for determining the method of surgically exposing an impacted canine. These include: the labiolingual position of the impacted crown; the vertical position of the tooth relative to the mucogingival junction; the amount of gingiva surrounding the impacted cuspid; and the mesiodistal position of the canine crown. [27] Based on these factors, an appropriate surgical technique can be chosen in order to optimize the esthetic outcome and reduce the difficulty of orthodontic treatment.

From an orthodontic perspective, the location of the canine will influence the direction and type of force utilized to align the canine. As previously stated, it may also modify the treatment plan and extraction pattern. One investigation demonstrated that when evaluating case difficulty and the direction of treatment, a significant difference was noted between 2-D and 3-D imaging. [21] In 29.5% of cases reviewed, a CBCT led the examiner to recommend a more active approach focused on expansion and space maintenance. [21] A separate study showed that in 18% of their patients, treatment plans varied dependent upon whether they were diagnostically viewed with a CBCT or a Panorex. [23] Evidence has also indicated that orthodontic treatment time

increased 3.4 months when a patient has a unilateral impaction, and 9.9 months with bilateral impactions. [29] Treatment time was found to be dependent upon the distance the impacted canine was from the occlusal plane. If it was less than 14mm, treatment time was on average 23.8 months, compared to 31.1 months if it was more than 14mm from the occlusal plane. Another study exhibited that treatment time was 9.8 months longer when the impaction was located mesial to the lateral incisor. [30] The same study also observed an increase in treatment time if the cusp tip of the impacted tooth was located further from the occlusal plane. Lastly, they detected a significant association between the amount of angulation and duration of treatment. As the ectopically erupting tooth was more horizontally angulated, the time in treatment increased. [30]

One of the many risks we are exposed to throughout life is the exposure to radiation from everyday activities. Medical and dental devices increase the amount of radiation we are exposed to. As practitioners it is our responsibility to determine if the risk of radiation exposure is a medically necessary diagnostic tool to benefit the patient during treatment. The average individual is exposed to 2400 μSv each year from normal background radiation. [32] That breaks down to 6.58 μSv per day. Panoramic x-rays and lateral cephalograms are commonly used diagnostic tools in the orthodontic practice. Each has been reported to have an effective dose of anywhere from 2.7 to 23 μSv and 10 μSv respectively. [33] [34] [35] [36]. Intra-oral radiographs have an effective dose of 8.3 μSv according to the European Commission in 2004 [32] and a full mouth series has a radiation exposure of 13-100 μSv. [33] Currently available CBCT units have been reported to have radiation exposure in the range of 30 to 206 μSv for a full craniofacial scan. [33][36] [37] Even lower effective doses have been observed when using a smaller dentoalveolar field of view. [36] Although the radiation from a CBCT is slightly higher in most instances, the accuracy and resolution of the image is more reliable. One study showed that measurement error was significantly lower using CBCT images as compared to a cephalogram when evaluating 76 measurements against a gold standard. [20] In fact, the 2-D image in one measurement showed an average error of 13.61mm, while the 3-D image had less than 1mm of error on average. The amount of error has been shown to be reduced when viewing images in the multiplanar (MPR) view, as compared to volume rendered (VR) and shaded surface displace (SSD) view modes. [19] The error seen in the VR and SSD modes may be attributed to surface contours being estimated in these perspectives. [19] Korbmacher et al. [38]conducted a study that demonstrated CBCT

provided more information regarding cleft lip and palate, impacted and retained teeth, root resorption, and third molars.

Bishara [1] stated, "The proper localization of the impacted tooth plays a crucial role in determining the feasibility of, as well as the proper access for, the surgical approach, and the proper direction for the application of orthodontic forces." Evidence has clearly shown the diagnostic value of a 3-D image when evaluating an impacted canine. Bjerklin and Ericson [39] showed that after viewing a CT image of a patient with an impacted canine, examiners changed their treatment plan almost 44% of the time based on the findings in the image. When comparing treatment planning using 2-D vs. 3-D imaging, Haney et al. [40] demonstrated that not only were Orthodontists more confident when utilizing a 3-D image, they modified their treatment plans 27% of the time. While there may be additional radiation exposure for patients, the benefits of CBCT images for diagnosis and adequate treatment planning of impacted maxillary canines has been well documented.

Rationale:

Breakthroughs in technology lead us to new ways to evaluate information. Previously, our diagnostic methods for locating impacted canines in 3 planes of space were limited. With the use of multiple two-dimensional radiographs, one could determine if a canine was located palatally or buccally to an adjacent tooth. [4] [31] However, the distance from that tooth was impossible to ascertain. In one study, they were only able to project the lateral incisor image away from that of the canine 37% of the time. [3] Accuracy was also a concern as the images could be distorted by magnifications and many structures were superimposed on one another. [21] With advancements in radiographic imaging, our diagnostic accuracy has greatly improved. However, protocols and standards on how to properly utilize this improved technology to determine the location and severity of an unerupted canine must be established. These innovations allow us to improve our diagnostic capacity as well as how we implement our treatment.

By viewing an impaction in three-dimensions we can locate and assess an impacted canine with great accuracy. Surgical planning of the exposure of the impacted canine as well as the proposed orthodontic forces needed to erupt the impacted canine into alignment with the dentition becomes more precise. The surgeon and orthodontist, as a team, now have more

significant information prior to active treatment. This can only lead to a better result and less potential for damage to adjacent teeth as well as the impacted tooth. However, once the three-dimensional location of a canine is established on a CBCT image, there does not exist adequate language to convey the entirety of its position and/or the severity of the impaction.

The objective of this study is to determine the location of impacted or unerupted maxillary canines and evaluate their position and severity as they correlate to the clinical aspect of orthodontics. This study hopes to establish a method to reliably locate an impacted canine from a sagittal, axial and a coronal view. The level and severity of the impaction will be measured by location and angulation related to other teeth and adjacent structures. Then with the impaction correlated to all three planes of space, a severity index can be utilized to help the clinician better determine the degree of impaction. The method described will be evaluated for reliability and accuracy.

Hypothesis

1. The maxillary canine tooth is generally impacted only at specific sites in the maxilla and CBCT imaging can accurately locate impacted canines in all 3 planes of space.
2. The method outlined to locate an impacted maxillary canine is reliable.

Specific Aims

1. To identify the specific regions which have a greater likelihood of canine impaction
2. To create an index along with a nomenclature to assist in classifying the location and severity of impacted maxillary canines.
3. Evaluate the methods of localization for reliability and accuracy.

.

Materials & Methods

Previous studies have shown ways to identify or assess the severity of maxillary impacted canines. Although these methods are effective, we propose to localize the impacted canines in a fashion that provides more information that is valuable to the clinician. Our methods will allow one to assess the severity of the impaction in terms of surgical exposure and biomechanical maneuvering of the tooth into the arch.

We reviewed approximately 1000 CBCT images of patients with impacted maxillary canines. From these images, 207 CBCT's, with 314 unerupted canines were selected to be analyzed. The images were collected from a diagnostic imaging center (Courtesy of Dr. David Hatcher and Dr. Francisco Eraso) and one office that specializes in Periodontics (Dr. Scott Ross), both located in the United States. No information regarding treatment or the reason the image was taken was known. The only information collected was the patient age and sex.

Individual images were classified as bilateral or unilateral and each impaction was treated as its own entity. The impaction was then characterized as unerupted or impacted. We defined an unerupted canine as impacted when its root development was complete or the contralateral canine was fully erupted. The presence of a primary canine on the side of impaction was recorded, as well as whether the patient was in appliances or a palatal expansion device. If any additional pathology, i.e. resorption, peg laterals, supernumerary teeth was observed it was documented as well. Each CBCT was then evaluated in the 3 planes of space as described below. Slice thickness was increased to 5mm to allow greater visibility of adjacent structures.

Sagittal View:

From this point of view, the incisal tip was identified based on its location related to the lateral or central incisor. If the lateral incisor was erupted with normal anatomy and an absence of pathology, it was used to identify the location of the canine. Otherwise, the central incisor was used as a reference. The CEJ (Cementoenamel junction) of the incisor was located as well as the root tip. The incisal tip of the impacted canine was then located as either 1) coronal to the incisor CEJ; 2) in the coronal ½ of the root; 3) in the apical ½ of the root; 4) or apical to the incisor root tip. Based on this position, the impaction was classified as Erupted, Low, Medium or High as shown below (Fig. 1). As mentioned previously, research has proven that as the distance of the impacted canine from the occlusal plane increases, treatment time and the probability of impaction increases, while periodontal health after treatment decreases. (16) (29) (28) (30) Therefore, this knowledge was incorporated into the severity index and as the impacted tooth was located more apically, the severity was increased (Fig. 1 & Table 1).

Figure 1

Point value assigned to canines based on location of incisal tip with respect to adjacent incisor

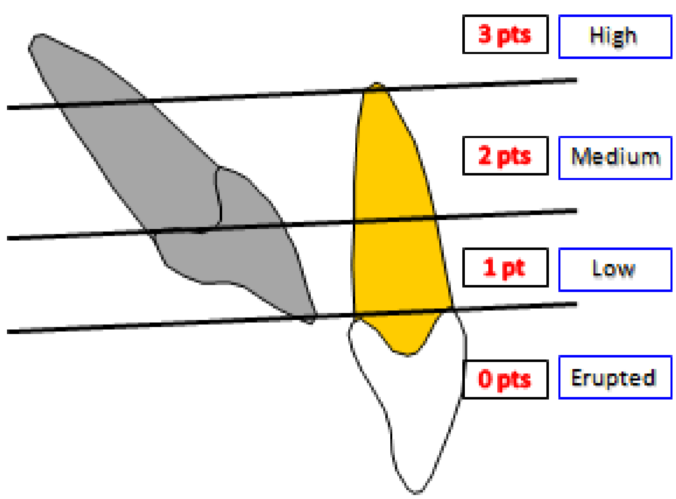


Table 1

Sagittal Location – Value & Classification		
Coronal to the CEJ:	0 points	**Erupted**
In the Coronal ½ of the root:	1 point	**Low**
In the Apical ½ of the root:	2 points	**Medium**
Apical to the root tip:	4 points	**High**

The angle created by the long axis of the tooth and a perpendicular line from the palatal plane was measured (Fig, 2) and labeled as torque. Based on this angle, the below point system was allotted to the impacted tooth (Table 2). For every 15 degrees away from the perpendicular plane, 1 point was assigned. The tooth angulation was also classified as positive or negative in relation to the perpendicular line.

Figure 2a

Point value assigned to canines based on angulation from the sagittal view

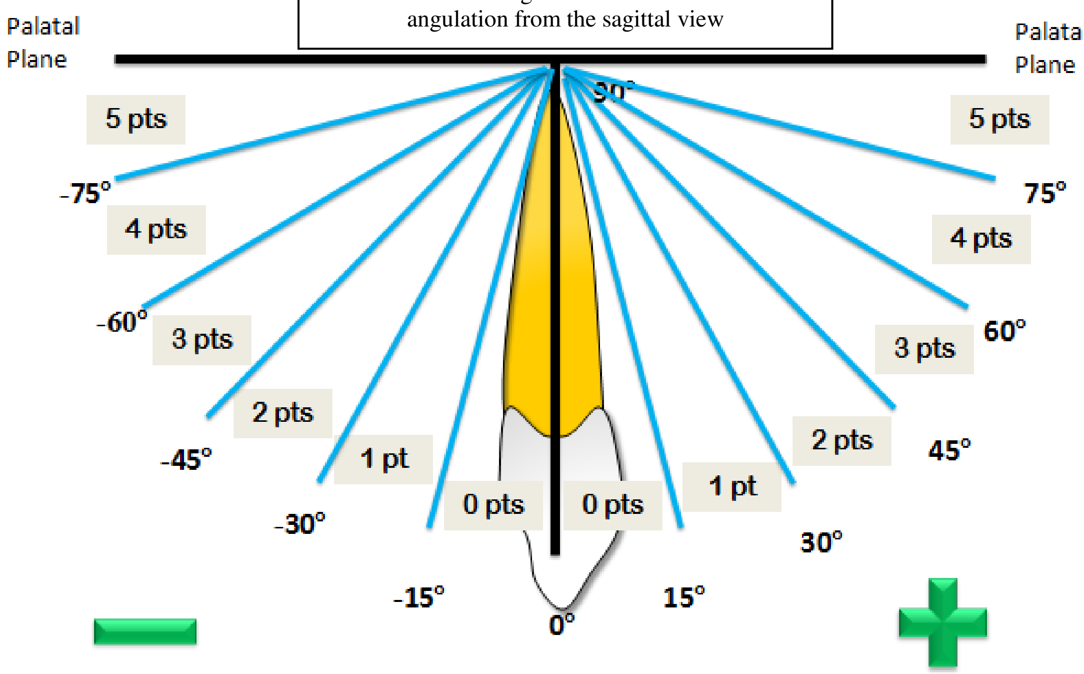


Figure 2b

Example of angular measurement from the sagittal perspective

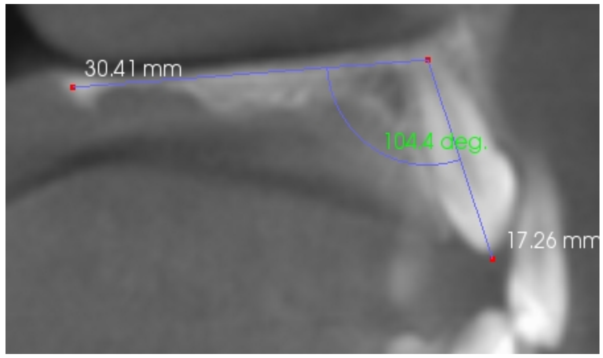


Table 2

Sagittal Angulation – Point Value	
>+ 75.01 degrees	5 points
+ 60.01 to 75 degrees:	4 points
+ 45.01 to 60 degrees:	3 points
+ 30.01 to 45 degrees:	2 points
+ 15.01 to 30 degrees:	1 point
0 to 15 degrees	**0 points**
- 15.01 to 30 degrees:	1 point
- 30.01 to 45 degrees:	2 points
- 45.01 to 60 degrees:	3 points
- 60.01 to 75 degrees:	4 points
< - 75.01 degrees	5 points

Axial View:

From this view, the cusp tip was located and then the buccal and palatal alveolar borders were identified. A line bisecting the alveolus was constructed and the distance from the closest alveolar border, palatal or buccal, to the incisal tip was measured. (Fig. 3) This measurement allowed us to calculate the distance from the midline of the alveolus. The cusp tip was designated as buccal, palatal or mid-alveolar based on its distance from the center of the alveolar bone. The mid-alveolus is defined as 1.5mm buccal or palatal to the midpoint between the alveolar borders. Severity increased in 1.5mm increments as the distance increased from the buccal and palatal cortical borders (Fig. 4). Since angulation in a buccal/palatal aspect was established in the sagittal view, it was unnecessary to do so in this view again. The following scale was assigned based on the findings in relation to the alveolar bisecting line in either a buccal or palatal direction (Table 3):

Figure 3

Example of the distance of a canine from the midline of the alveolus viewed from the axial perspective

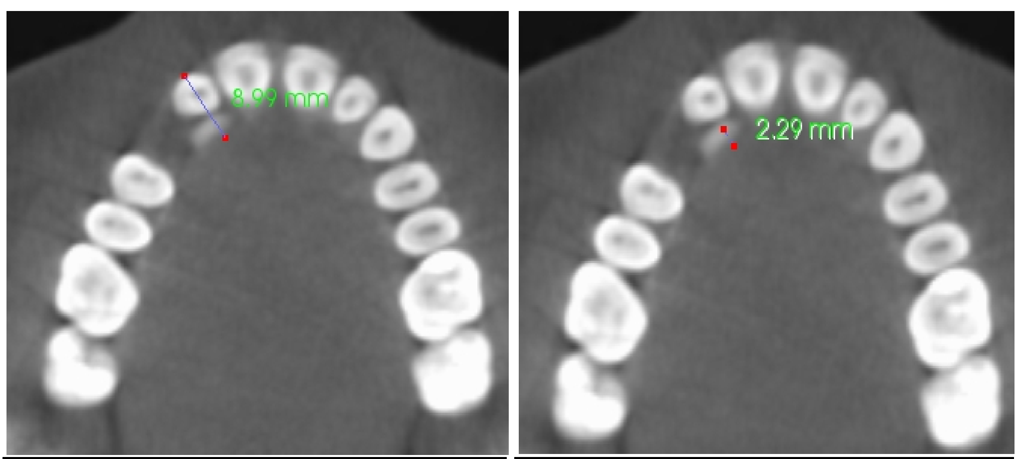


Figure 4

Increments in 1.5mm based on distance from the midline of the alveolus

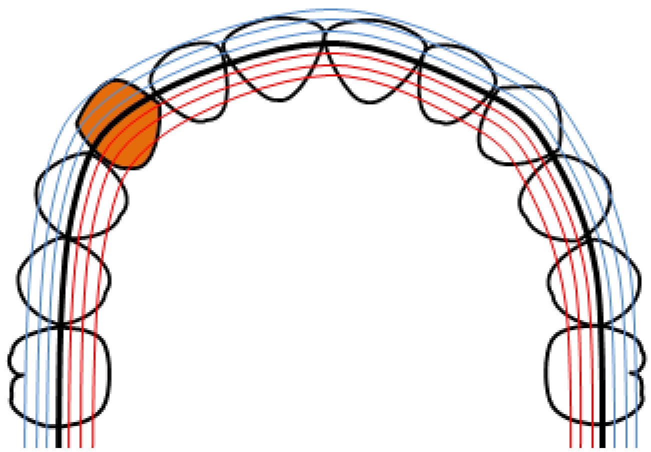


Table 3

Axial Location		
↑ + 4.5 to 5.99mm:	↑ 3 points	↑ Buccal 3
+ 3.0 to 4.49mm:	2 points	Buccal 2
+ 1.5 to 2.99mm:	1 point	Buccal 1
0 to +/- 1.49mm:	0 points	Mid-Alveolar
- 1.5 to 2.99mm:	1 point	Palatal 1
- 3.0 to 4.49mm:	2 points	Palatal 2
- 4.5 to 5.99mm: ↓	3 points ↓	Palatal 3 ↓

Coronal View:

From this viewpoint, we assessed the impacted maxillary canine in relation to the adjacent teeth. After identifying the cusp tip of the canine; the mesial, distal and long axis of the adjacent lateral incisor, central incisor and 1st premolar were differentiated (Fig. 5). Studies have shown that the likelihood of impaction, resorption and duration of treatment were all increased if the impacted canine is located mesial to the distal border of the lateral incisor. (15) (17) (30) (16) It has also been proven that periodontal health decreases as the impacted tooth overlaps the midline of the lateral incisor. (28) In fact, the majority of studies have shown this to be the most important factor in predicting impactions and resorption. (15) (18) The canine cusp tip was then classified and scored as follows (Figure 6):

Figure 5

Example of the location of a canine from a coronal perspective in relation to the adjacent dentition.

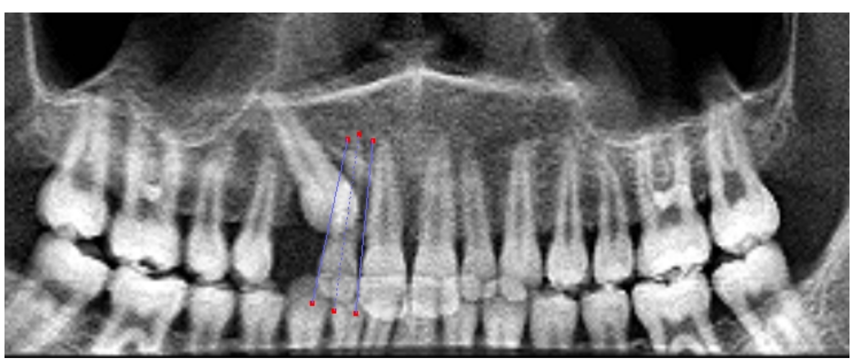
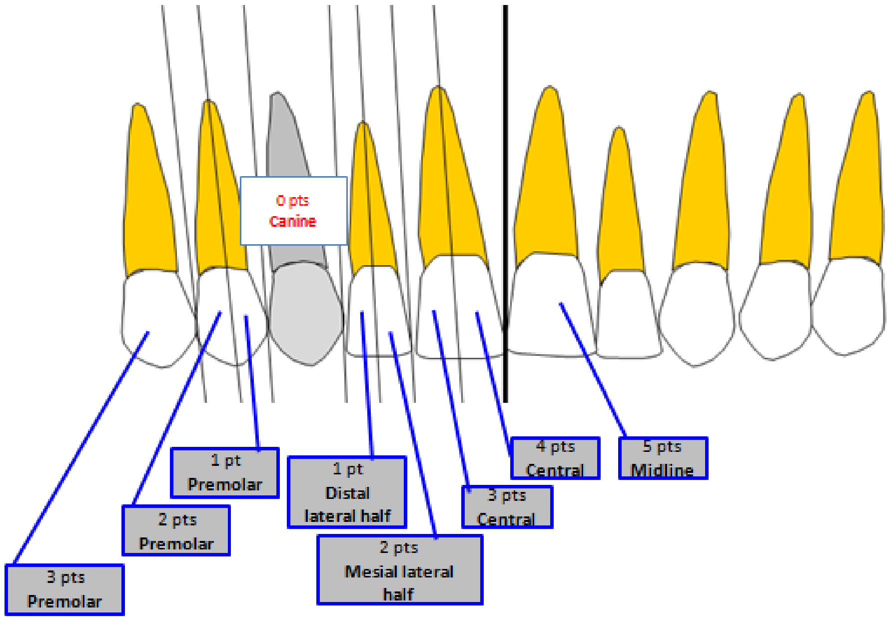


Figure 6

Point value assigned to canines based on location to adjacent dentition from a coronal perspective



The angulation of the impacted maxillary canine was also assessed in a mesial-distal aspect. The long axis of the tooth was identified as well as the skeletal midline through ANS (Fig. 7). The angle created by these two lines was used to classify the tooth as shown in Figure 8 and Table 4:

Figure 7

Example of angular measurement of a canine from the coronal view

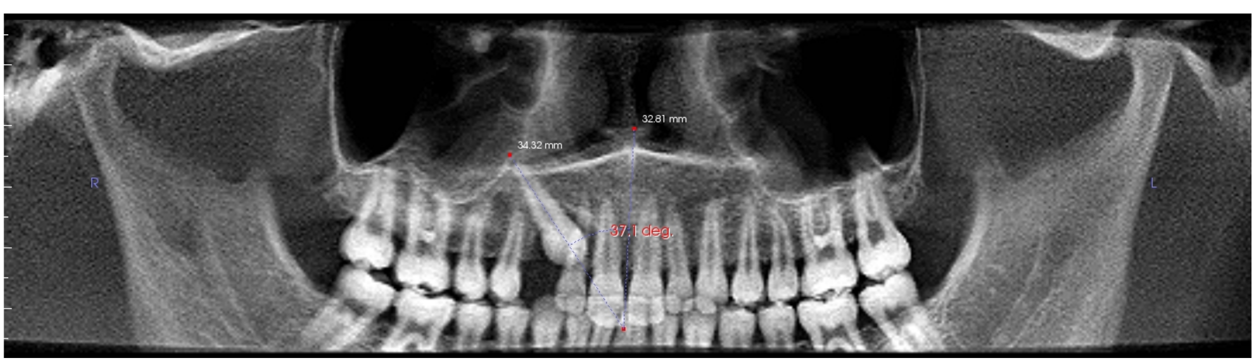


Figure 8

Point value and classification assigned to canines based on angulation from the coronal perspective

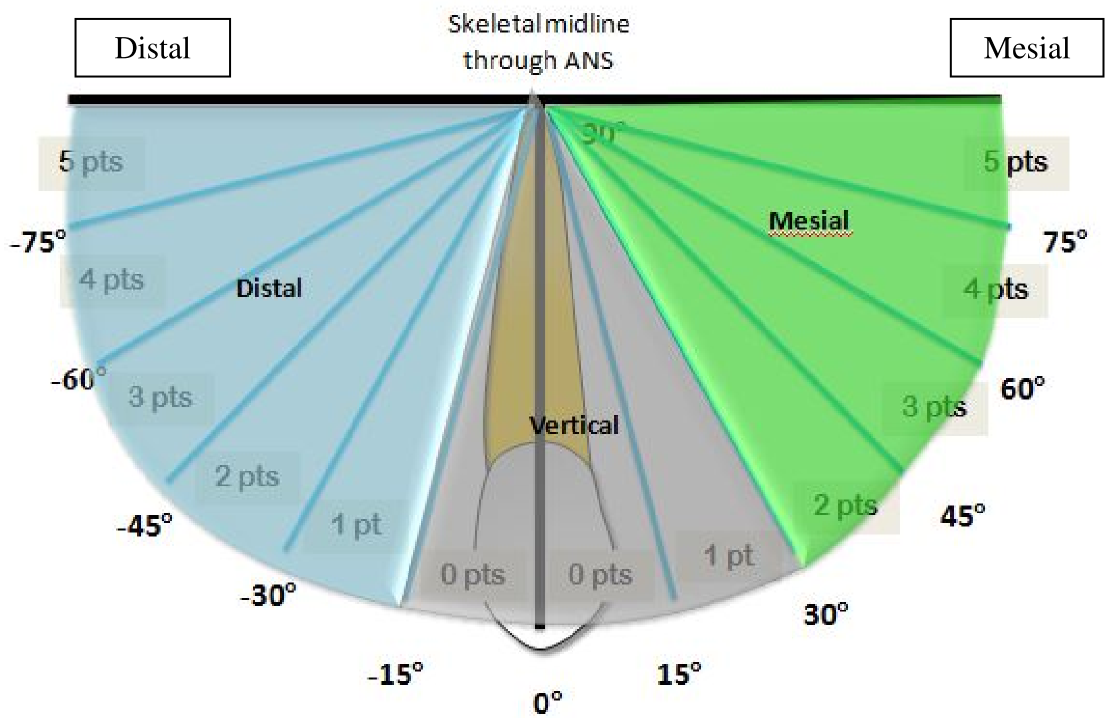


Table 4

Coronal Location – Value & Classification	
0 to - 15 degrees: 0 points	**Vertical** ↓
0 to 15 degrees: 0 points	
15.01 to 30 degrees: 1 point	
30.01 to 45 degrees: 2 points	**Mesial** ↓
45.01 to 60 degrees: 3 points	
60.01o 75 degrees: 4 points	
>75.01 degrees: 5 points	
-15.01 to -30 degrees: 1 point	

-30.01 to -45 degrees: 2 points	**Distal**
-45.01 to -60 degrees: 3 points	↓
-60.01 to -75 degrees: 4 points	
< -75.01 degrees: 5 points	

Classification

Once the images were evaluated as noted above, the scores were combined to measure severity. The classification index is designed to allow the clinician to be able to visualize the impacted maxillary canine. The impaction was identified as follows based on the above guidelines.

1. From an axial view the tooth was designated as:

    Buccal

    Palatal

    Midalveolar

A number followed this nomenclature to designate how many increments of 1.5mm the canine tip was located from the middle of the alveolus.

2. From the sagittal view, the tooth was classified as:

    Erupted: Coronal to the CEJ of the adjacent incisor

    Low: Coronal to the midpoint of the root of the adjacent incisor

    Medium: In the apical ½ of the root of the adjacent incisor

    High: Apical to the root tip of the adjacent incisor

    It was also given a positive (+) or negative (-) classification to illustrate the angulation. A number followed this sign to depict the amount of torque the canine displayed.

3. From a coronal point of view the impaction was identified as:

    Normally Erupting: Distal to the lateral incisor and mesial to the premolar

    D-Lateral: Mesial to the distal border of the lateral incisor, but distal to its midpoint

    M-Lateral: Mesial to the midpoint of lateral, but distal to the central incisor

    Central: Mesial to the distal border of central incisor

Midline: Crossing the maxillary dental midline

Premolar: Distal to the mesial border of the premolar

4. Also from the coronal view, the canine was classified as:

   Vertical: Angulation was between -15° to + 30° from the skeletal midline through ANS

   Mesial: Angle was greater than 30° in a mesial direction

   Distal: Angle was less than -15° in a distal direction

5. Finally, using the point system outlined above, a severity was determined.

   0 to 5 points: Mild

   6 to 10 points: Moderate

   More than 10 points: Severe

An impacted canine was then classified as:

Buccal 2; High, +3 torque; M-Lat; Mesially tipped; Moderate impaction.

A simplified version of this index was also created to portray a basic classification:

Buccal; High; M-Lat; mesially tipped; Moderate impaction.

Following are the inclusion and exclusion criteria for patient selection:

Inclusion criteria:

1. CBCT images of unilateral or bilateral impacted or unerupted maxillary canines.

Exclusion criteria:

1. Missing Central incisor
2. Impacted Central incisor

Forty canine images were reviewed 30 days apart for intrarater reliability. The same images were evaluated by a separate examiner (Dr. Vishwanath) for interater reliability. The examiner underwent minimal training (30 min) regarding measurement of the CBCT images.

A typodont setup with an impacted canine was also utilized to assess our methods. Measurements were made on the typodont with a digital caliper. A CBCT image of the typodont

was also evaluated in the same fashion as described above. These results were compared with each other to determine accuracy.

Statistical Analysis:

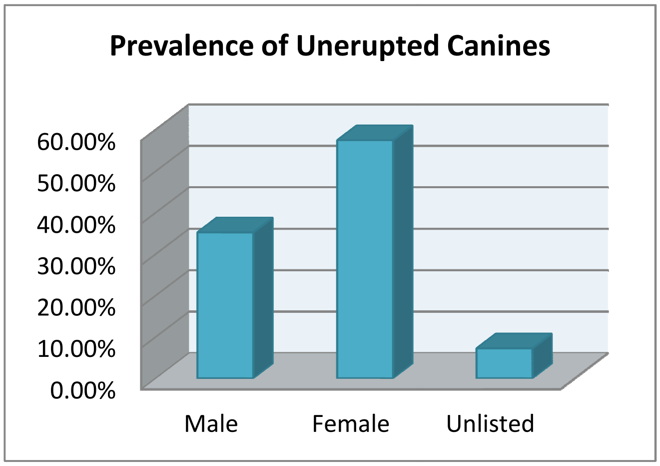
Simple descriptive statistics were used to summarize the data. Intra- and inter-examiner reliability was examined by using Cohen-Kappa values for categorical variables and Cronbach Alpha (intra-class correlation coefficients) for continuous variables. Kappa values were computed for 10 variables and intra-class correlation coefficients for 3 variables. Outcomes were compared between right and left sides and also by gender. For categorical variables, Chi-square tests were used while Mann-Whitney U test was used for continuous variables. One of the primary dependent variables was severity of case (mild, moderate, and severe). The effects of age (each 1 year increase in age), gender, axial class, and location on severity were examined by multivariable logistic regression models. Since severity of case was a polynomial variable, two regression models were used to examine the outcome. In the first regression model the odds of having a severe case compared to mild or moderate was examined. In the second regression model, the odds of having a mild case compared to a moderate or severe case was examined. The maximum likelihood methods were used to fit the multivariable logistic regression model. Model fitness was examined by Hosmer and Lemeshow Goodness of fit test statistic. The effects of age, gender, use of orthodontic appliances, use of maxillary expansion appliance, and presence of primary canine on total points was examined by a multivariable linear regression model. Ordinary least squares approach was used to fit the regression model. All statistical tests were two-sided and a p-value of <0.05 was deemed to be statistically significant. All statistical analyses were conducted using SPSS Version 22.0 software (IBM Inc, Research Triangle Park, NC).

2).

Results

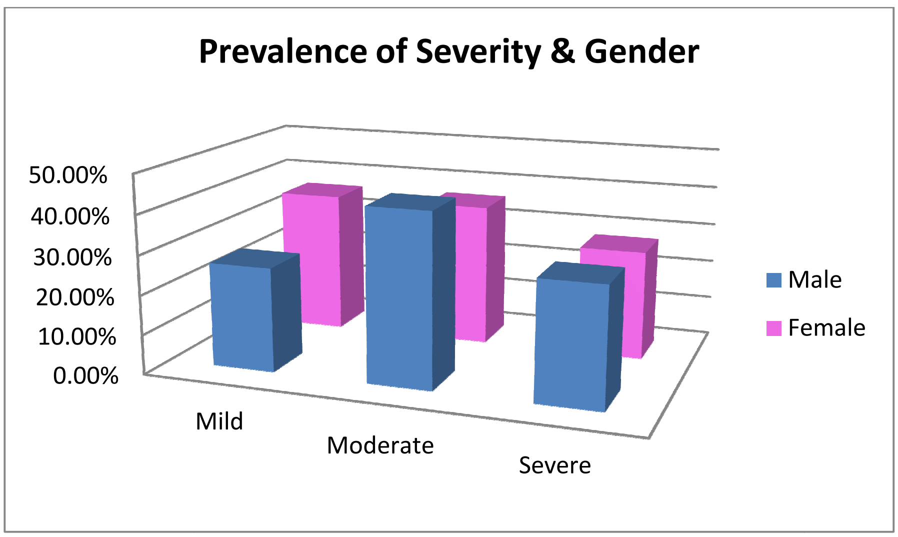
Our study evaluated 207 patients with 314 unerupted maxillary canines. Of these, 140 were defined as unerupted, while 174 were classified as impacted. Of the patients, 57.49% (119) were female, 35.27% (73) male, and 7.25% (15) were unreported, giving females a 1.63 greater chance than males of having an unerupted/impacted canine (Table 5, Chart 1). Bilateral impactions were present in 51.69% of patients, while right and left presentation appeared to be equally distributed at 51.91% and 48.09%, respectively. Males and females demonstrated similar patterns of bilateral impactions; 50.68% of males and 49.37% of females exhibited the trait. Males were found to have a greater likelihood of having a moderate impaction, 43.64% to 36.16% of females; however this finding was not significant. Females were more likely to have a mild impaction, 36.16% vs. 23.35% in males; this was also not statistically significant (Chart 2).

Chart 1 Table 5



Prevalence of Unerupted Canines		
	Patients	Percentage
Male	73	35.27%
Female	119	57.49%
Unlisted	15	7.25%
Bilateral	107	51.69%
Unilateral	100	49.31%
Right	56	56.00%
Left	44	44.00%

Chart 2



Overall, palatal and buccal impactions seemed to be observed at the same prevalence, 38.54% and 40.76%, respectively. 20.70% of the canines were classified as midalveolar (Table 6, Chart 3). There was no difference seen between males and females and this measurement. However, it was observed that as age increased, palatal impactions became more common. Patients above the age of 13 had an occurrence of 63.57% of palatally displaced canine, with 23.26% buccally displaced and 13.18% midalveolar. When compared to patients 13 or younger, 21.08% were palatal, 52.97% were buccal and 25.95% were midalveolar (Chart 4).

Chart 3

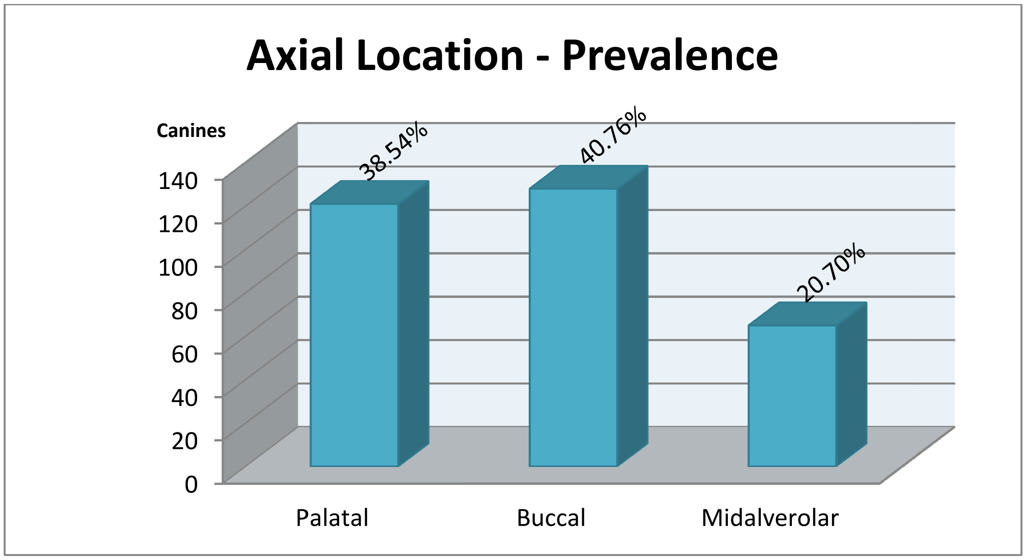
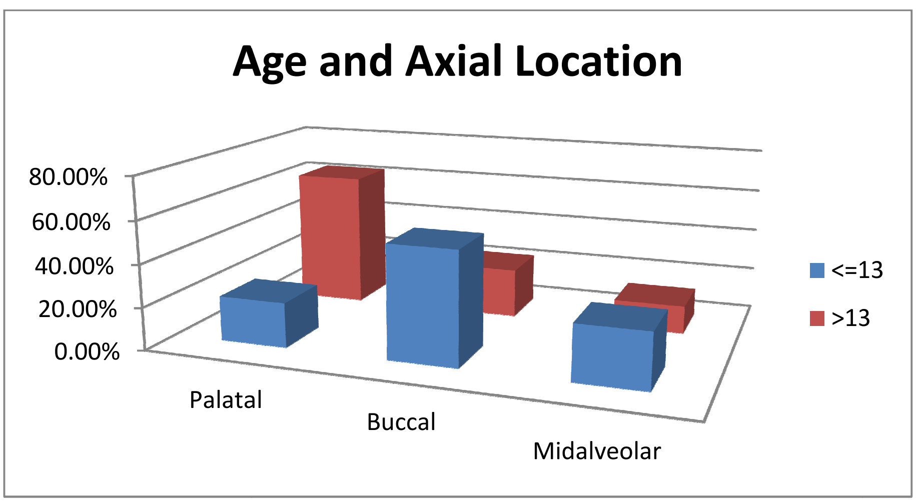


Table 6

Axial Location		
Palatal	121	38.54%
Buccal	128	40.76%
Midalveolar	65	20.70%
Total	314	

Chart 4



The vertical position of the canine appeared to be unaffected by sex or age. 5.73% of the canines were located apical to the root tip, 22.61% in the apical ½ of the root, 48.41% in the coronal ½ of the root, and 23.25% coronal to the CEJ (Fig. 9). Coronal position revealed the canine normally positioned in 34.08% of cases, 16.56% crossing the distal border of the lateral incisor but distal to its midline, 19.43% in the mesial of the lateral but distal to the central incisor, 23.57% positioned in the region of the central incisors, and 2.55% crossing the dental midline (Chart 5). 3.82% were found in the region of the premolar. As the age of the patient increased beyond the age of 13 there was a greater likelihood for the canine to be located in the region of the central incisor. 41.09% of impactions were located in the central incisor region when patients were older than ... r younger (Chart 6).

Figure 9

Prevalence of canines based on location of incisal tip with respect to adjacent incisor

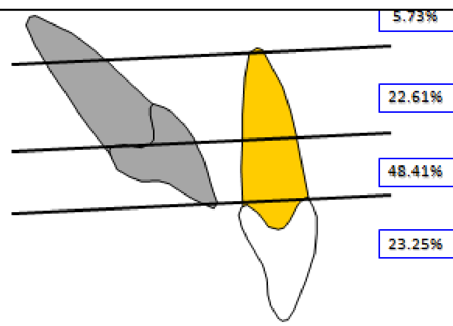


Chart 5

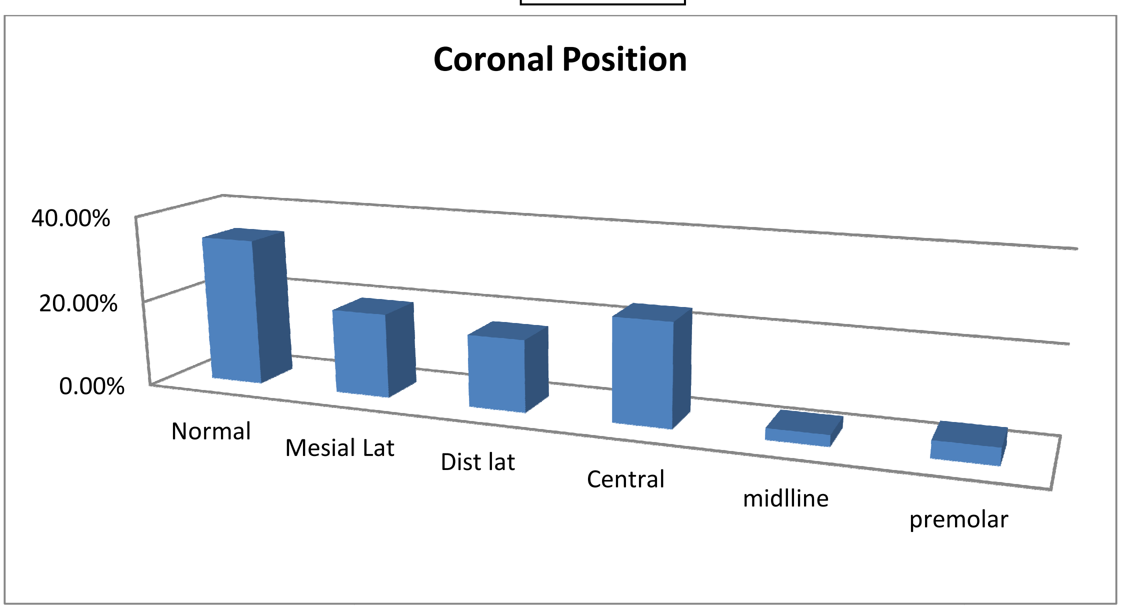
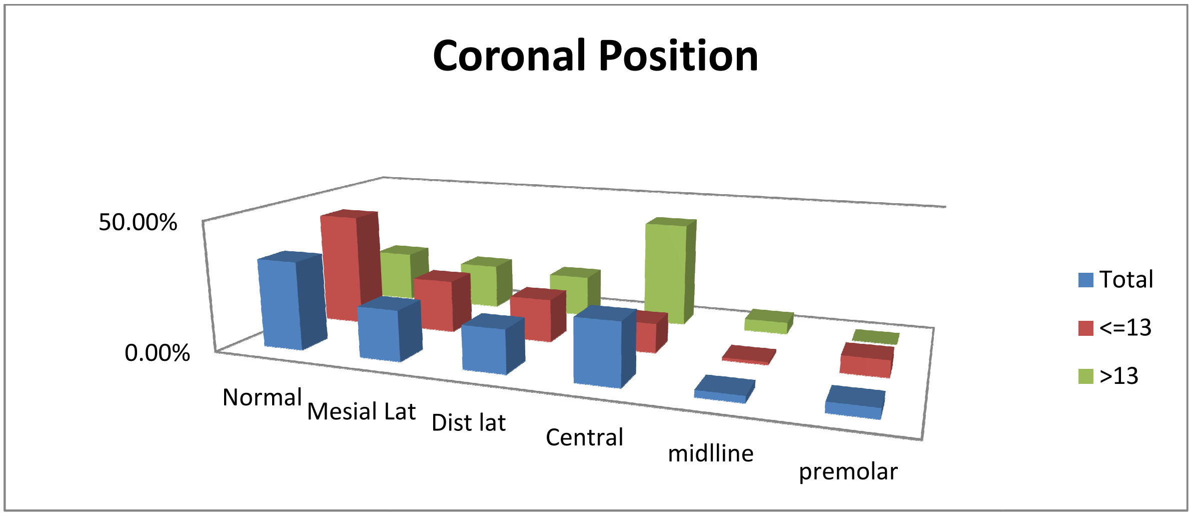


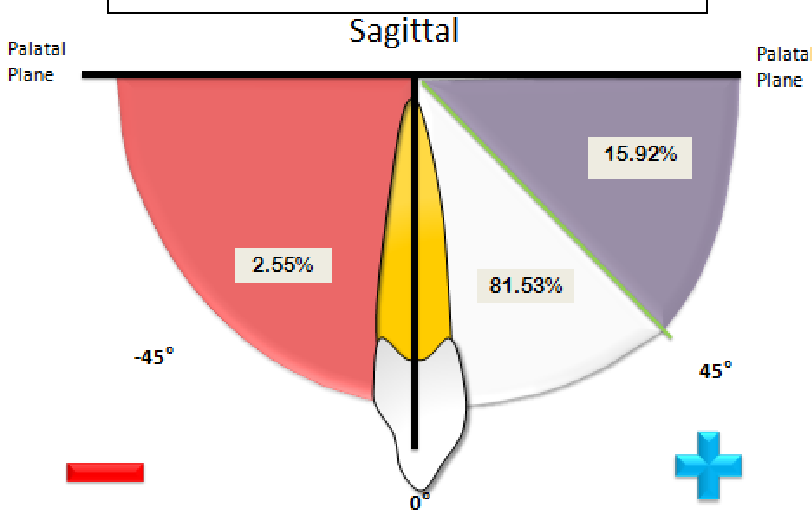
Chart 6



15.92% of impactions had a torque value greater than 45 degrees, while 81.53% had a value between 0 and 45 degrees (Figure 10). 2.55% of the canines had torque values that were negative, indicating the cusp tip was angulated towards the palatal side. These values were similar in both males and females, along with patients older than 13 and 13 or younger.

Figure 10

Prevalence and classification of canines based on angular torque from a sagittal view



The coronal angulation ("tip") of the canine presented mesially tipped in 59.24% of the cases, distally tipped in 0.64% of impactions, and 40.13% were vertical (Fig. 11). A similar pattern was observed for males and females. Patients older than 13 years of age, however,

showed a greater chance of being mesially angulated, with 78.29% mesially angulated, and 21.71% vertical (Chart 7). Patients 13 or younger were more likely to have a vertically tipped canine, occurring in 52.97% of the cases, while 45.95% were mesially tipped.

Figure 11

Prevalence and classification of canines based on angulation from a coronal view

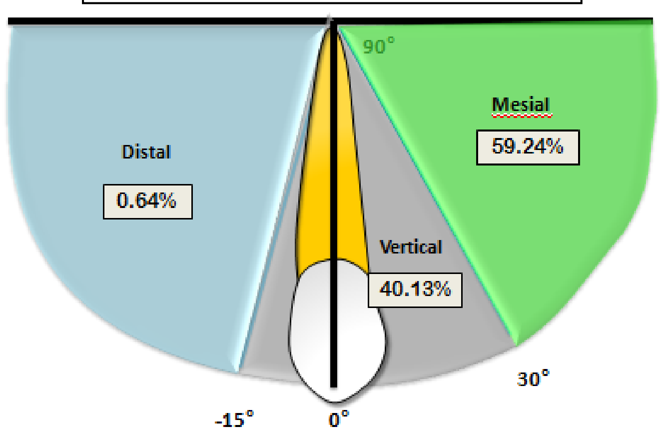
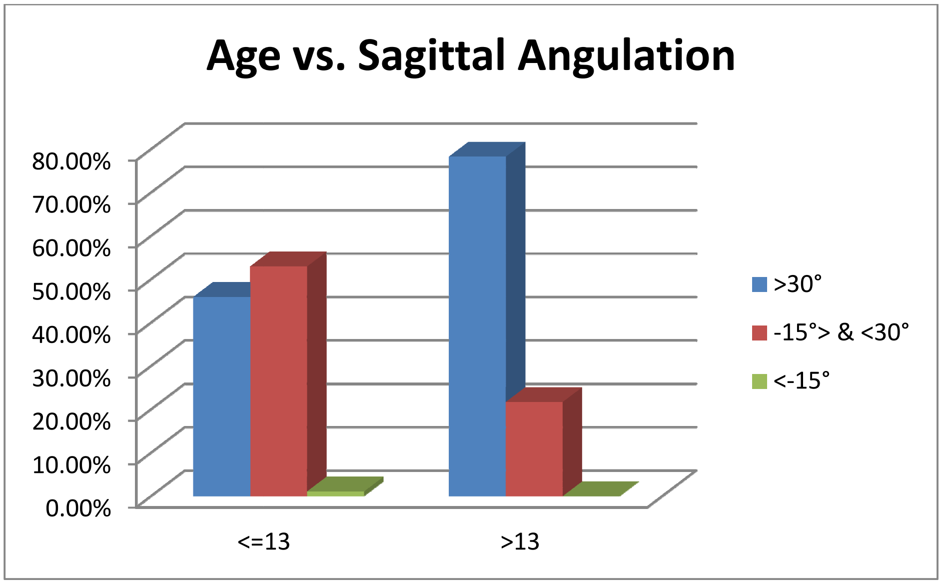


Chart 7



33.44% of the canines were classified as mild, 37.58% moderate and 28.98% severe (Chart 8, Table 7). As stated before the sex of the patient did not have a significant effect on the severity of the impaction. It was observed that as the age of a patient increased, severity also increased. With each yearly increase in age, the chance of having a severe impaction increased by 3.2% (OR 1.032, P-value .041), (Chart 9). Patients 13 years or younger had a greater prevalence of mild impactions 43.24% compared to 19.38% in patients that were older than 13. Severe impactions were observed in 41.86% of canines in the older age group compared to 20% of those 13 or younger (Chart 10). 46% of unilateral impactions were classified as severe, which is greater than that observed for bilateral impactions (21.03%). The buccal/palatal location also affected the severity, as one would expect. If the canine was positioned buccally the impaction was severe 4.947 times more than if it was positioned midalveolar (p-value .001). If positioned palatally, it was 3.767 times more likely to be severe than if located midalveolar (p-value .006).

Table 7

Severity		
Mild	105	33.44%
Moderate	118	37.58%
Severe	91	28.98%
Total	314	

Chart 8

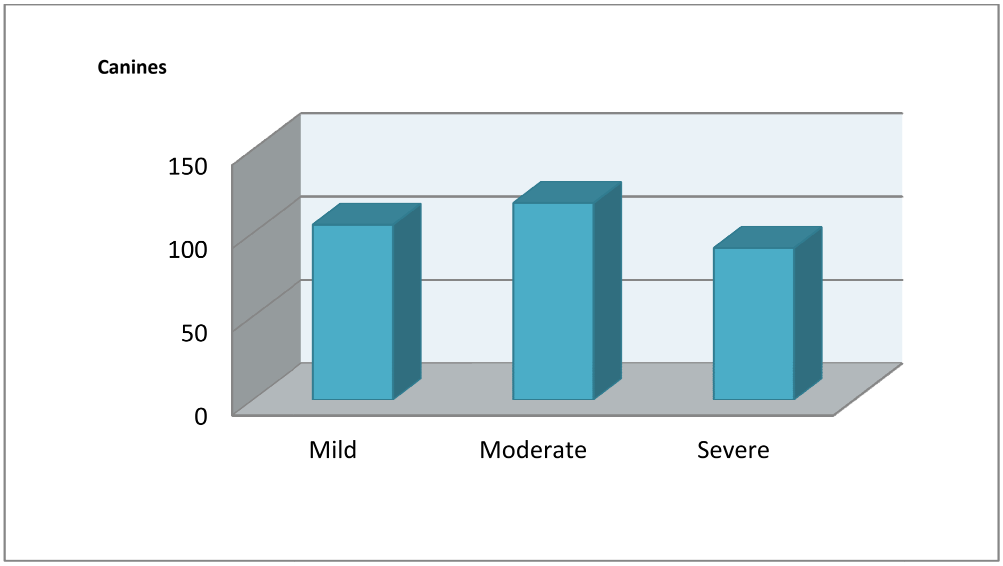


Chart 9

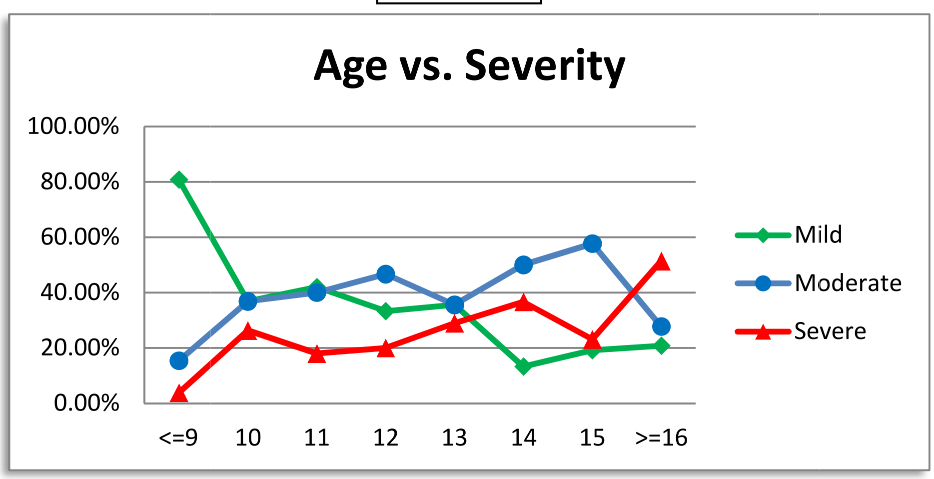
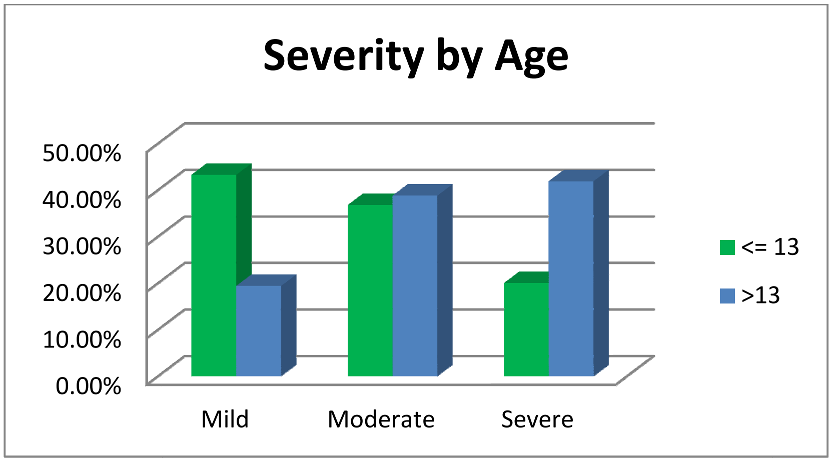


Chart 10



Of the 314 unerupted canines, 46% had a primary canine on the affected side. The presence of a primary canine did not appear to influence severity or position of the impacted/unerupted canine. Even as patient's age increased, there was no effect observed on severity or location of the impaction due to the primary canine. 27% of the patients were in appliances and 3% had a palatal expansion device. Neither of these factors appeared to influence the location or severity of the impaction. Certain anomalies were recorded when observed adjacent to the unerupted canine. The observations showed 9 cases with Peg laterals, 17 with missing lateral incisors, 11 cases with supernumerary teeth, and resorption was documented in 22 cases. These associations did not appear to have an effect on the location or severity of the unerupted canine.

Forty canine images were reviewed for interater and intrarater reliability. The images were examined 30 days apart for the intrarater analysis. Analysis revealed good inter-examiner reliability for measuring axial deviations from the midline and excellent inter-examiner and intra-examiner reliability for all other variables. A typodont setup with an impacted canine was also utilized to compare measurements. Results showed very high similarity between CBCT measurements and those achieved using a digital caliper.

Full Statistical results are shown in the Appendix.

Discussion

Two hundred seven patients with CBCT images of 314 unerupted/impacted canines were included in our study for evaluation. According to literature, a canine has been defined as

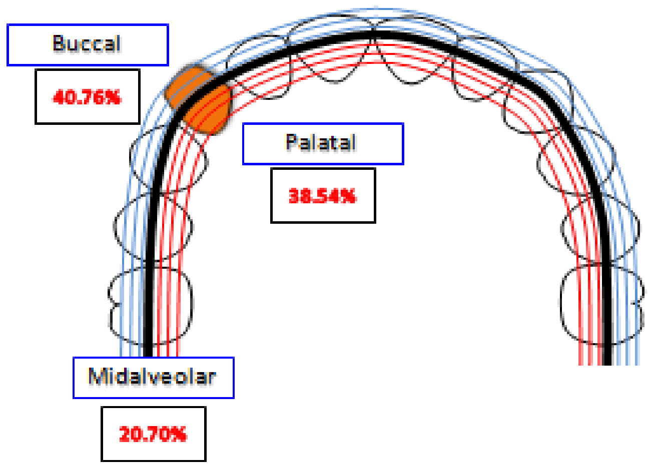
impacted when the tooth was unerupted after complete root development and when the contralateral canine was fully erupted.[42] Another study considered canines impacted when their roots were fully developed but the teeth were still covered with bone or mucosa.[43] Since our study included patients with bilateral presentation of impacted/unerupted canines, we defined an unerupted canine as impacted when its root development was complete or the contralateral canine was fully erupted. From this description we characterized 140 as unerupted and 174 were classified as impacted.

Females are reported to be more commonly affected by canine impaction, occurring approximately twice as frequently as males. [44][1][9] Our study showed similar results, with females 1.63 times more likely to be affected by an unerupted/impacted canine. When diagnosed as impacted, that ratio increased to 1.93:1. Bilateral impactions have been shown to occur in approximately 8% to 20% of patients with impacted canines. [11][45][1] The results of our study concluded 51.69% of patients had bilateral unerupted canines. This frequency is regarded as high compared to some studies, however numerous others studies have shown similar rates of bilateral impactions.[9][13][46] This effect may be due to the population sample, as Asian populations appear to have a lower frequency of bilateral impactions. [45][11] Studies showing more frequent bilateral impactions have Middle-Eastern populations or patients from the United States, as in our study. [13][46][9]

It has been reported that palatal impactions are approximately 2 to 3 times more common than labial displaced canines. [17][46][13] The results of our study showed an equivalent prevalence between buccal and palatal impactions. We found 38.54% to be located palatally and 40.76% buccally displaced (Fig. 11). This is similar to more recent studies that also utilized CBCT images. [11][41] This may be due to the sample populations, as Asian subjects are more likely to have a labial or midalveolar position of an impacted canine. [10] It is important to note that our results did show that as age increased palatal impactions became more common. 63.57% of patients above the age of 13 had a palatal location while 23.26% were buccally located. When comparing this to patients 13 or younger, 21.08% were palatal and 52.97% were buccal. These results also correlated with impactions defined as impacted compared to unerupted. Impacted canines were palatally located in 60.34% of the cases and buccal in 28.16%. These results show that once a canine is defined as impacted, it is more likely to be palatally displaced, at a ratio of 2.14:1 when compared to buccal displacement. This finding is more consistent with most studies

Figure 11
Prevalence of canines based on canine incisal tip in relation to alveolar border from an axial view

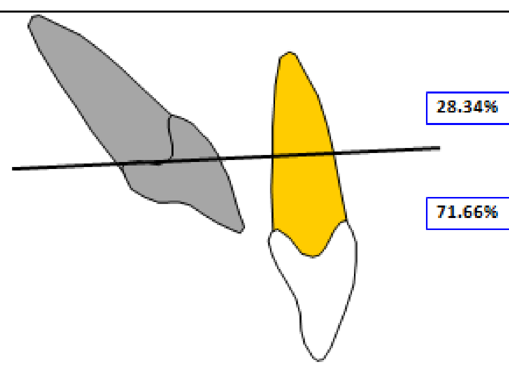
of European and American populations as well as with the accepted wisdom within Orthodontics.



Previous studies have shown that the vertical position of an erupting canine can significantly influence the likelihood of impaction.[16] Periodontal health and treatment time have also been proven to be significantly affected by the distance of an impacted canine to the occlusal plane. In our study, 28.34% of the unerupted canines were located in the apical ½ of the root or above the root tip (Fig. 12). Based on previous studies, we can infer canines positioned above the midpoint of the adjacent incisor root would have a greater probability for adverse effects and an extended duration of treatment. It was also observed that this frequency did not change with age or when comparing impacted vs. unerupted canines.

Figure 12

Prevalence of canines apical and coronal to the midpoint of the adjacent incisor root based on location of the canine incisal tip



Studies have shown that the likelihood of impaction, resorption and treatment time all increased if the impacted canine is located mesial to the distal border of the lateral incisor. [15] [30] [16][11][18][41] The periodontal health and the probability of eruption once the deciduous canine was extracted were both significantly decreased when the impacted canine crossed the midline of the lateral incisor. [17][28] These studies utilized conventional panoramic images, or those generated from a CBCT. The results of our study showed the canine was normally positioned in 34.08% of cases. 62.10% were found to be located mesial to the distal border of the lateral incisor. 45.54% were located mesial to the midline of the lateral incisor (Fig. 13). This indicates that at least 60% of impacted canines are expected to have a greater chance for added treatment complexity. Patients older than 13 had a higher percentage of impacted canines in these regions, with 79.84% located mesial to the distal border of the lateral incisor and 63.57% mesial to the midline of the lateral incisor (Fig. 14). In addition, impactions located in the region of the central incisor increased when patients were above the age of 13. 41.09% of impactions were located in the central incisor region of patients older than 13, compared to 11.35% of those 13 or younger. Similar percentages were documented when the canine was diagnosed as impacted.

Figure 13

Prevalence of canines located mesial to adjacent lateral incisor from a coronal view

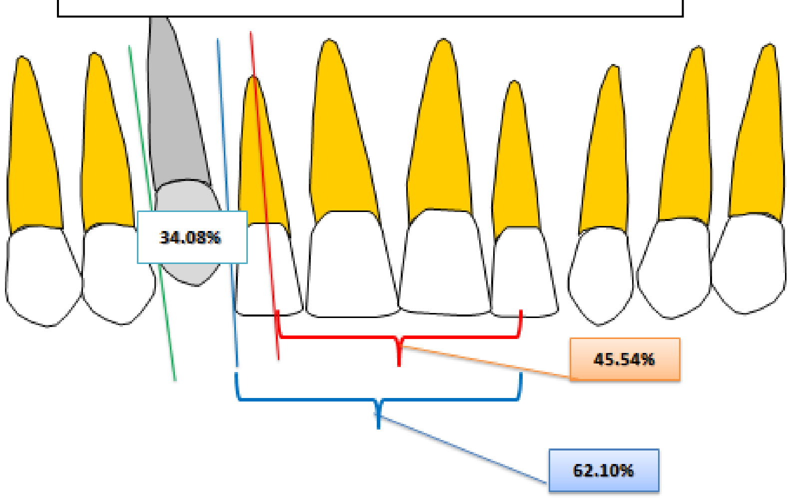
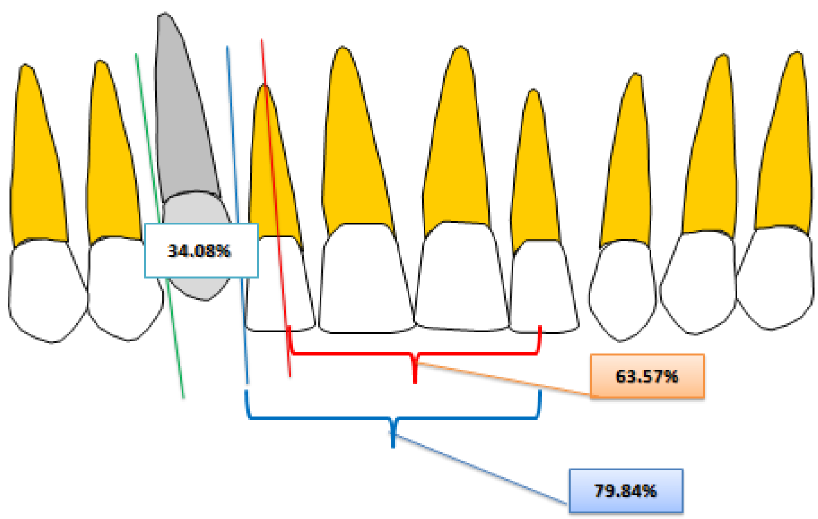


Figure 14

Prevalence of canines located mesial to adjacent lateral incisor for patients above the age of 13; from a coronal view

Patient's >13 years of age



Angulation from a sagittal perspective demonstrated that 15.92% of impactions had a value greater than 45 degrees when compared to the palatal plane, indicating a less than ideal path to eruption. While no literature has shown significant implications of this angle, it can be assumed that an impaction positioned less vertically may have difficulty erupting. From a clinical perspective, the initial torque of the canine may create challenges in achieving the proper angulation in the 3rd order and possibly compromise esthetics. Prescriptions for modern straight-wire appliances have torque values for maxillary canines ranging from 0 to -7 degrees.[49] Some clinicians have advocated using brackets with excessive negative torque value in order to accomplish the proper 3rd order angulation.[48] From a surgical perspective, the angulation may dictate where the bonded attachment is placed on the crown of the canine. Based on these clinical implications, the torque of an unerupted canine must be taken into consideration during diagnosis.

The angulation of an unerupted canine from a frontal perspective has been shown to influence the likelihood of impaction, risk of resorption, the duration of treatment, and the chances of normal eruption if the deciduous canine is extracted.[16][18][26][30] Our study classified the unerupted canine as mesially tipped, vertical, or distally tipped in relation to the skeletal midline through ANS. A mesially tipped canine was defined as an angle greater than 30 degrees. This angle is based on 2 previous studies showing: 1) The risk of resorption increased by 50% when this angle exceeded 25 degrees;[18] 2) The probability of normal eruption after extraction of the deciduous canine significantly decreased when the angulation surpassed 31 degrees.[26] In

addition, similar studies have shown that as this angle increased, the duration of treatment and the likelihood of impaction also increased.[16][30] We observed mesially tipped canines in 59.24% of the cases, distally tipped in 0.64%, and 40.13% were classified as vertically angulated. Patients older than 13 years of age were shown to have a greater chance of a mesially angulated canine, with 78.29% mesially angulated, and 21.71% vertical. Similar findings were recorded for canines that were diagnosed as impacted vs. unerupted. Patients 13 or younger were more likely to have a vertically tipped canine, occurring in 52.97% of the cases, while 45.95% were mesially tipped. This indicates that severity and probability of adverse effects increases with age and diagnosis of impaction.

Based on our classification system 33.44% of the canines were identified as mild, 37.58% moderate, and 28.98% severe. The sex of the patient did not have a significant effect on the severity of the impaction. Age, however, was shown to significantly affect severity. As the age of a patient increased, severity also increased. With each yearly increase in age, the chance of having a severe impaction increased by 3.2% (OR 1.032, P-value .041). In addition, severe impactions were observed in 41.86% of canines in the patients above the age of 13 compared to 20% in those 13 or younger. 46% of unilateral impactions were classified as severe, which is greater than that observed for bilateral impactions (21.03%). As expected a buccal or palatal position was considered more severe than a midalveolar impaction, since this position directly influences the calculation of severity. If the canine was positioned buccally the impaction was severe 4.947 times more than if it was positioned midalveolar (p-value .001). If positioned palatally, it was 3.767 times more likely to be severe than if located midalveolar (p-value .006).

Inter-examiner and Intra-examiner reliability were found to be excellent for almost all measurements. This reflects the reproducibility of the method described to locate an unerupted/impacted canine using CBCT. While previous studies have evaluated impacted canines with three-dimensional images, the diagnostic accuracy of their methods was not described.[47] By comparing our measurements using the CBCT image of a typodont with an impacted canine, to those calculated using a digital caliper, we were able to evaluate the accuracy of our method. The results showed very high similarity between the CBCT measurements and those achieved using a digital caliper.

Lastly, measurements recorded for each canine were utilized to develop an index of nomenclature. All 314 canines were classified according to this index. Clinically, this allows for

improved communication between Orthodontists, Surgeons and other dental specialties. The index will assist in more accurate description of the specific location, angulation and severity of an unerupted or impacted maxillary canine. As a result, more ideal treatment and surgical techniques can be utilized. This may lead to enhanced esthetics, reduced treatment time and decreased adverse effects.

Conclusion

Our analysis of 204 patients with 314 unerupted maxillary canines showed 140 defined as unerupted and 174 classified as impacted. The method outlined to analyze impacted canines using CBCT exhibited excellent inter-examiner and intra-examiner reliability for all variables except axial deviations from the midline which exhibited good inter-examiner reliability. Measurements using a digital caliper on a typodont were compared to those acquired from a CBCT image of the same typodont. Results showed very high similarity between the image and caliper measurements.

Females were reported to be affected 1.63 times more frequently than males. 119 (57.49%) of the patients were female, 73 (35.27%) were male, and 15 (7.25%) were unreported. Bilateral expression was observed in 51.69% of patients. No significant difference was observed between right and left unerupted canines. Once a canine was defined as impacted, females were observed to be affected 1.93 times more frequently than males.

Palatally displaced canines were observed at a rate of 38.54% compared to 40.76% for buccal displacement and 20.70% of the canines were located midalveolar. However, once a canine was defined as impacted, palatal impaction was 2.14 times more likely.

The results of our study demonstrated that 34.08% of canines were normally positioned, 62.10% were found to be located mesial to the distal border of the lateral incisor and 45.54% were located mesial to the midline of the lateral incisor. One could conclude that at least 60% of impacted canines would be expected to have a greater chance for adverse effects. When the canine was defined as impacted or the patient was older than 13 years of age this percentage increased.

The torque value of an unerupted canine may influence treatment difficulty and esthetic outcome. 15.92% of canines evaluated exhibited angulation greater than 45 degrees when compared to the palatal plane, indicating excessive positive torque. Clinicians should consider the torque value of an unerupted canine during diagnosis and treatment planning. When evaluating the angulation from a frontal view, mesially tipped canines were observed in 59.24% of the cases. It was also observed that 78.29% of canines were mesially angulated once defined as impacted or when the patients were older than 13. This indicates that severity and probability of adverse effects increases with age or diagnosis of impaction.

Our evaluation classified the unerupted canines by severity based on their location and angulation. 33.44% of the canines were identified as mild, 37.58% moderate, and 28.98% severe. As the age of a patient increased, severity was found to significantly increase. With each yearly increase in age, the chance of having a severe impaction increased by 3.2% (OR 1.032, P-value .041). Buccal or palatal position was considered more severe than a midalveolar impaction. If the canine was positioned buccally the impaction was severe 4.947 times more than if it was positioned midalveolar (p-value .001). If positioned palatally, it was 3.767 times more likely to be severe than if located midalveolar (p-value .006).

The presence or absence of active appliances, a primary canine, or a palatal expansion device did not appear to influence severity or position of the impacted/unerupted canine. Other anomalies such as peg laterals, a missing lateral incisor, supernumerary teeth or resorption did not seem to influence the degree of impaction.

All 314 canines were classified according to the index described. The index was designed to improve the quality of communication between dental specialists when diagnosing the location and severity of an unerupted or impacted maxillary canine.

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Appendix A

Chart 11

Prevalence of “impacted” canines by Gender

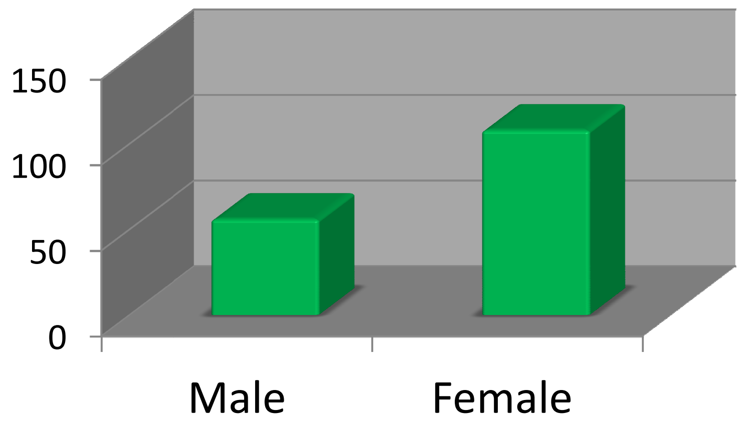


Chart 12

Prevalence of "impacted" canines bilateral or Unilateral

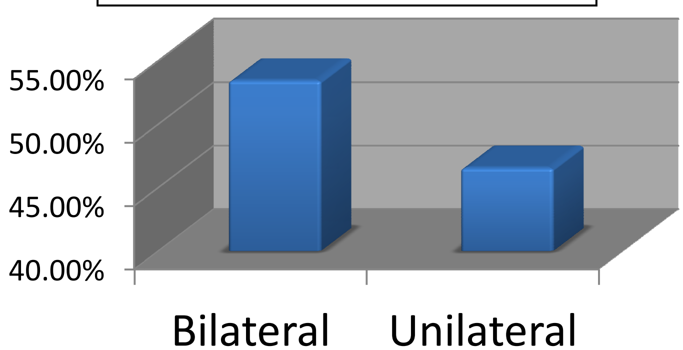


Figure 15

Prevalence of "impacted" canines based on location of incisal tip with respect to adjacent incisor

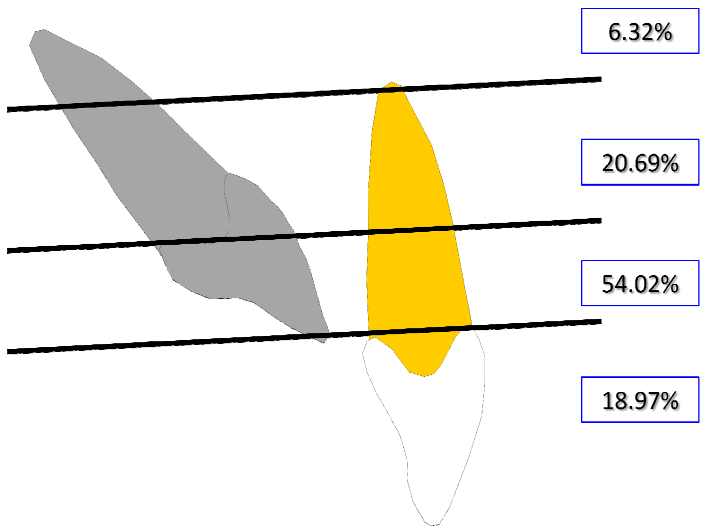


Figure 16

Prevalence of "impacted" canines based on location of incisal tip with respect to adjacent incisor

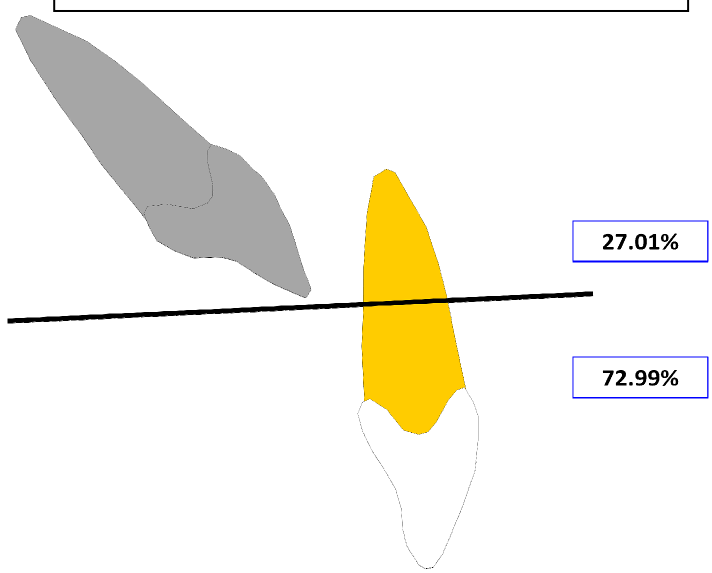


Figure 17

Prevalence and classification of "impacted" canines based on angular torque from a sagittal view

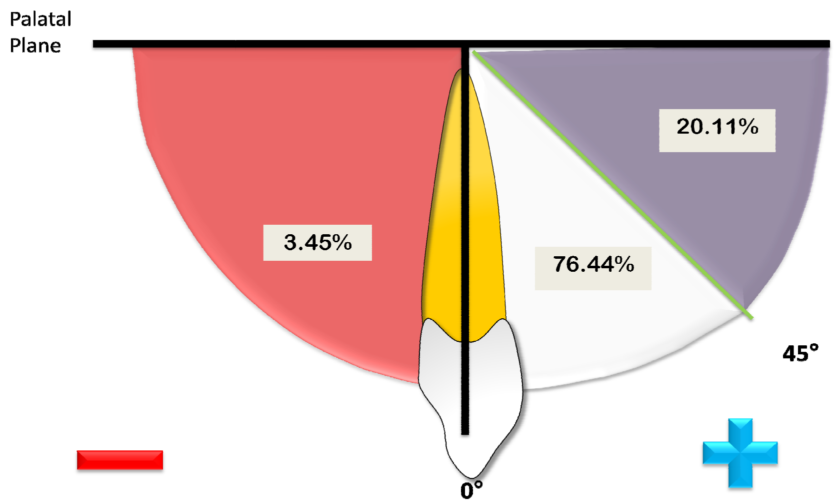


Figure 18
Prevalence of "impacted" canines based on canine incisal tip in relation to alveolar border from an axial view

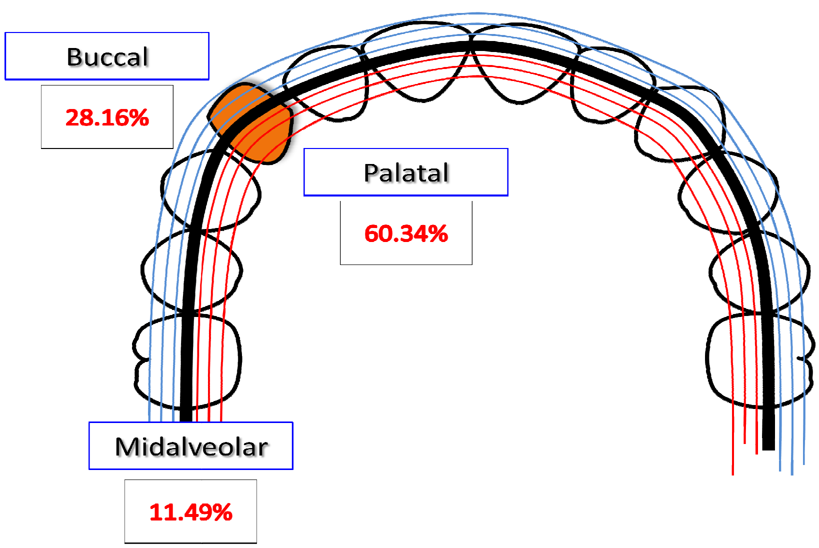


Figure 19

Prevalence of "impacted" canines by location from a coronal view

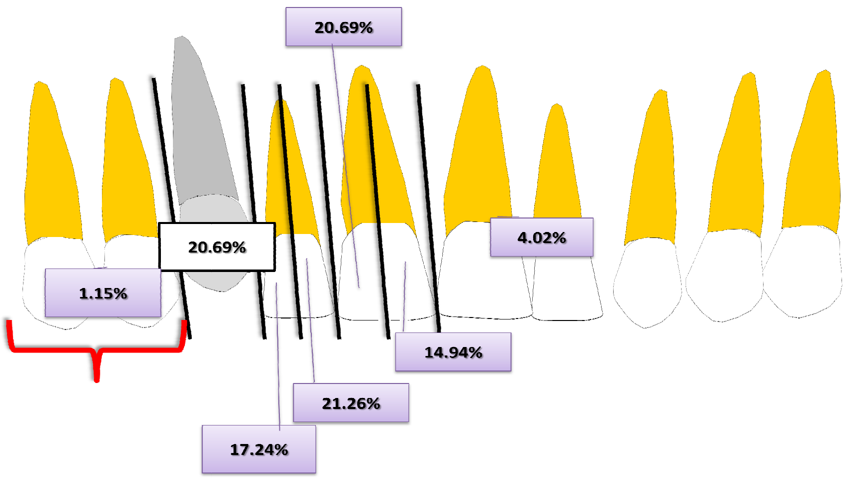


Figure 20

Prevalence of "impacted" canines located mesial to adjacent lateral incisor; from a coronal view

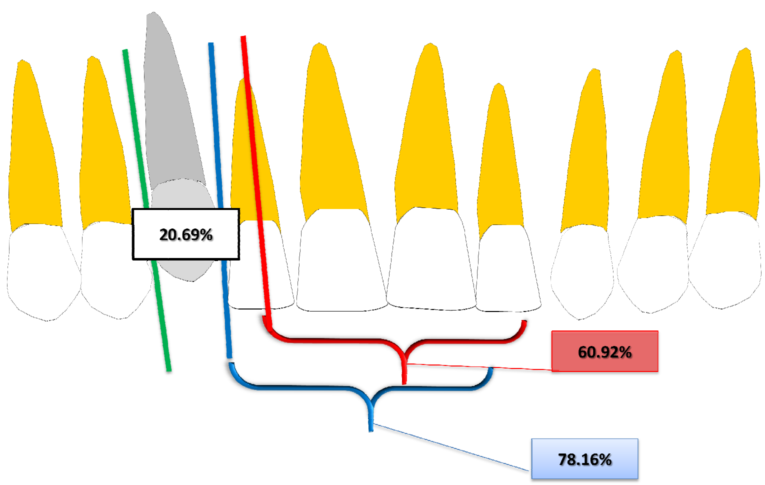


Figure 21

Prevalence and classification of "impacted" canines based on angulation from a coronal view

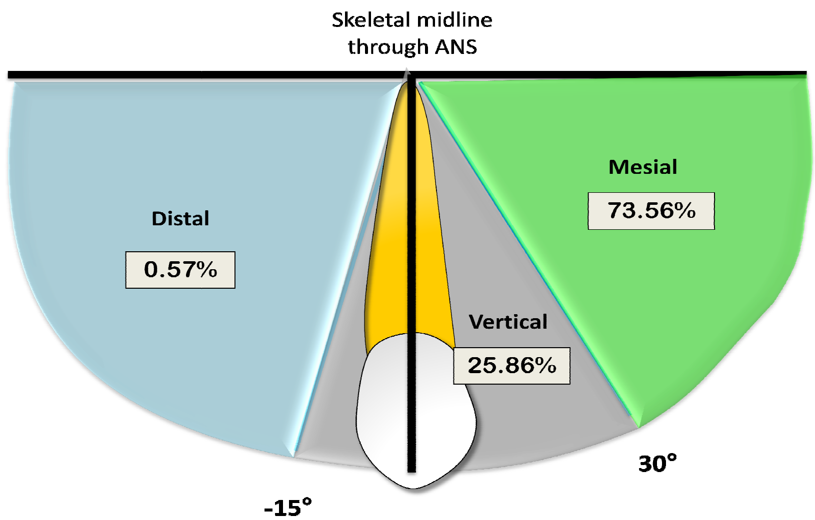
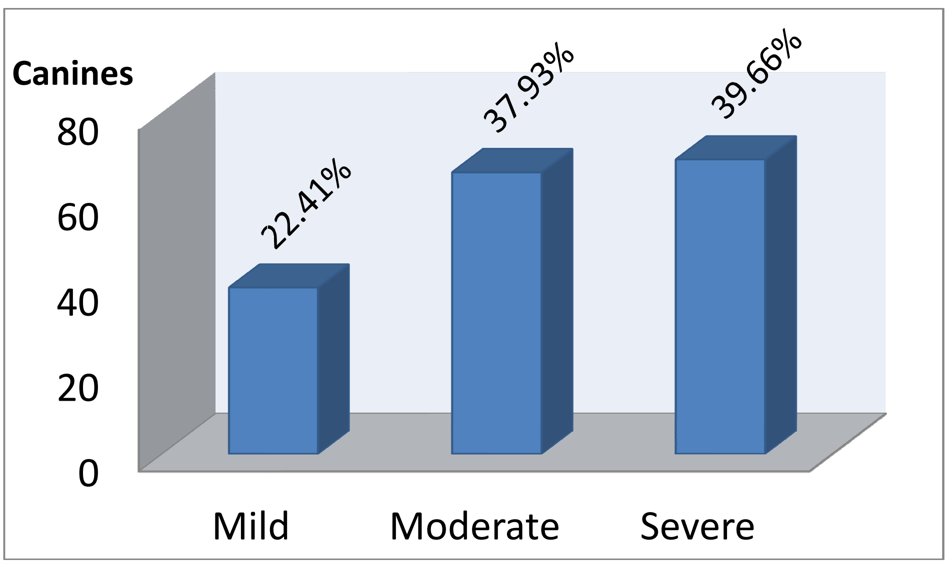


Chart 13

Prevalence of "impacted" canines based severity



Appendix B

Statistical Data: Courtesy of Sath Purush

Gender :

Chi-square tests

Position:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.047[a]	1	.828		
Continuity Correction[b]	.009	1	.924		
Likelihood Ratio	.047	1	.828		
Fisher's Exact Test				.903	.462
Linear-by-Linear Association	.047	1	.829		
N of Valid Cases	287				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 52.89.

b. Computed only for a 2x2 table

Unilateral or Bilateral:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.091[a]	1	.762		
Continuity Correction[b]	.030	1	.862		
Likelihood Ratio	.092	1	.762		
Fisher's Exact Test				.798	.432
Linear-by-Linear Association	.091	1	.763		
N of Valid Cases	287				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 37.18.

b. Computed only for a 2x2 table

Impacted or Unerupted:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.830[a]	1	.093		
Continuity Correction[b]	2.433	1	.119		
Likelihood Ratio	2.823	1	.093		
Fisher's Exact Test				.111	.060
Linear-by-Linear Association	2.820	1	.093		
N of Valid Cases	287				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 47.14.

b. Computed only for a 2x2 table

Appliances:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.691[a]	1	.030		
Continuity Correction[b]	4.114	1	.043		
Likelihood Ratio	4.619	1	.032		
Fisher's Exact Test				.039	.022
Linear-by-Linear Association	4.675	1	.031		
N of Valid Cases	287				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 29.13.

b. Computed only for a 2x2 table

Expander:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.682[a]	1	.030		
Continuity Correction[b]	3.222	1	.073		
Likelihood Ratio	4.575	1	.032		
Fisher's Exact Test				.058	.038
Linear-by-Linear Association	4.666	1	.031		
N of Valid Cases	287				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.07.

b. Computed only for a 2x2 table

Primary Canine:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.024[a]	1	.876		
Continuity Correction[b]	.001	1	.973		
Likelihood Ratio	.024	1	.876		
Fisher's Exact Test				.904	.486
Linear-by-Linear Association	.024	1	.876		
N of Valid Cases	287				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 51.36.

b. Computed only for a 2x2 table

Sagittal Location:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.386[a]	3	.496
Likelihood Ratio	2.312	3	.510
Linear-by-Linear Association	.393	1	.531
N of Valid Cases	287		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.13.

Axial Class:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.533[a]	2	.766
Likelihood Ratio	.534	2	.766
Linear-by-Linear Association	.520	1	.471
N of Valid Cases	287		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 22.61.

Axial Deviations from the midline:

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.506[a]	5	.004
Likelihood Ratio	17.261	5	.004
N of Valid Cases	287		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.37.

Coronal Location:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.449[a]	5	.265
Likelihood Ratio	6.326	5	.276
Linear-by-Linear Association	.098	1	.755
N of Valid Cases	287		

a. 3 cells (25.0%) have expected count less than 5. The minimum expected count is 2.30.

Coronal Points:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.000[a]	5	.221
Likelihood Ratio	6.908	5	.228
Linear-by-Linear Association	.094	1	.759
N of Valid Cases	287		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 2.30.

Coronal Angulation (Tip):

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.305[a]	2	.116
Likelihood Ratio	4.356	2	.113
Linear-by-Linear Association	3.538	1	.060
N of Valid Cases	287		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is .77.

Severity:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.754[a]	2	.252
Likelihood Ratio	2.791	2	.248
Linear-by-Linear Association	1.489	1	.222
N of Valid Cases	287		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 31.43.

T-Test

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Age	Female	176	15.27	9.090	.685
	Male	110	15.28	7.638	.728
Axial_Value	Female	177	3.366282485875706	2.174606779861835	.163453454855117
	Male	110	3.568681818181819	2.171919697654792	.207084417855944
Coronal_Value	Female	177	37.1097	20.83094	1.56575
	Male	110	41.1355	23.31073	2.22259
Sagittal_Angle	Female	177	108.6864	41.78394	3.14067
	Male	110	115.4355	41.94504	3.99930
Total Points	Female	177	7.58	4.242	.319
	Male	110	8.35	4.244	.405

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Age	Equal variances assumed	.004	.949	-.014	284
	Equal variances not assumed			-.015	260.330
Axial_Value	Equal variances assumed	.460	.498	-.767	285
	Equal variances not assumed			-.767	231.479
Coronal_Value	Equal variances assumed	.227	.634	-1.520	285
	Equal variances not assumed			-1.481	211.738
Sagittal_Angle	Equal variances assumed	.030	.862	-1.328	285
	Equal variances not assumed			-1.327	230.585
Total Points	Equal variances assumed	.089	.765	-1.482	285
	Equal variances not assumed			-1.482	231.197

Independent Samples Test

		t-test for Equality of Means		
		Sig. (2-tailed)	Mean Difference	Std. Error Difference
Age	Equal variances assumed	.989	-.015	1.041
	Equal variances not assumed	.988	-.015	1.000
Axial_Value	Equal variances assumed	.444	-.202399332306113	.263896419741446
	Equal variances not assumed	.444	-.202399332306113	.263819991704209
Coronal_Value	Equal variances assumed	.130	-4.02579	2.64830
	Equal variances not assumed	.140	-4.02579	2.71873
Sagittal_Angle	Equal variances assumed	.185	-6.74901	5.08052
	Equal variances not assumed	.186	-6.74901	5.08510
Total Points	Equal variances assumed	.139	-.764	.515
	Equal variances not assumed	.140	-.764	.515

Independent Samples Test

		t-test for Equality of Means	
		95% Confidence Interval of the Difference	
		Lower	Upper
Age	Equal variances assumed	-2.063	2.033
	Equal variances not assumed	-1.984	1.954
Axial_Value	Equal variances assumed	-.721832620141435	.317033955529210
	Equal variances not assumed	-.722194672720169	.317396008107943
Coronal_Value	Equal variances assumed	-9.23850	1.18691
	Equal variances not assumed	-9.38503	1.33345
Sagittal_Angle	Equal variances assumed	-16.74911	3.25109
	Equal variances not assumed	-16.76822	3.27019
Total Points	Equal variances assumed	-1.777	.250
	Equal variances not assumed	-1.779	.251

Nonparametric Tests

Mann-Whitney Test

Ranks

	Sex	N	Mean Rank	Sum of Ranks
Age	Female	176	142.49	25077.50
	Male	110	145.12	15963.50
	Total	286		
Sagittal_Angle	Female	177	137.81	24392.00
	Male	110	153.96	16936.00
	Total	287		
Axial_Value	Female	177	139.56	24702.50
	Male	110	151.14	16625.50
	Total	287		
Coronal_Value	Female	177	138.89	24584.00
	Male	110	152.22	16744.00
	Total	287		

Test Statistics[a]

	Age	Sagittal_Angle	Axial_Value	Coronal_Value
Mann-Whitney U	9501.500	8639.000	8949.500	8831.000
Wilcoxon W	25077.500	24392.000	24702.500	24584.000
Z	-.264	-1.603	-1.149	-1.322
Asymp. Sig. (2-tailed)	.792	.109	.251	.186

a. Grouping Variable: Sex

Right vs. Left Position:

<u>Chi-squared test</u>

Sagittal Location:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.016[a]	3	.797
Likelihood Ratio	1.017	3	.797
Linear-by-Linear Association	.832	1	.362
N of Valid Cases	314		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.66.

Axial Class:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.045[a]	2	.978
Likelihood Ratio	.045	2	.978
Linear-by-Linear Association	.002	1	.963
N of Valid Cases	314		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 31.26.

Axial Deviations from midline:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.547[a]	5	.474
Likelihood Ratio	4.671	5	.457
N of Valid Cases	314		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.18.

Coronal Location:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.695[a]	5	.594
Likelihood Ratio	3.709	5	.592
Linear-by-Linear Association	1.527	1	.217
N of Valid Cases	314		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 3.85.

Coronal Points:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.775[a]	5	.582
Likelihood Ratio	3.792	5	.580
Linear-by-Linear Association	2.284	1	.131
N of Valid Cases	314		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 3.85.

Coronal Angulation:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.685[a]	2	.710
Likelihood Ratio	.686	2	.710
Linear-by-Linear Association	.616	1	.433
N of Valid Cases	314		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is .96.

Severity:

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.738[a]	2	.419
Likelihood Ratio	1.741	2	.419
Linear-by-Linear Association	.566	1	.452
N of Valid Cases	314		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 43.76.

T-Test

Group Statistics

	Position	N	Mean	Std. Deviation	Std. Error Mean
Sagittal_Angle	Left	151	112.6556	42.84600	3.48676
	Right	163	111.9288	38.75972	3.03590
Axial_Value	Left	151	3.353013245033115	1.991696938079870	.162081998157926
	Right	163	3.743386503067486	2.460698453804823	.192736777821184
Coronal_Value	Left	151	40.0020	22.10274	1.79870
	Right	163	36.9203	22.60191	1.77032
Total Points	Left	151	8.09	4.256	.346
	Right	163	7.72	4.484	.351

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Sagittal_Angle	Equal variances assumed	.005	.941	.158	312
	Equal variances not assumed			.157	302.607
Axial_Value	Equal variances assumed	5.035	.026	-1.538	312
	Equal variances not assumed			-1.550	306.565
Coronal_Value	Equal variances assumed	.125	.724	1.220	312
	Equal variances not assumed			1.221	311.079
Total Points	Equal variances assumed	.588	.444	.746	312
	Equal variances not assumed			.748	311.812

Independent Samples Test

		t-test for Equality of Means		
		Sig. (2-tailed)	Mean Difference	Std. Error Difference
Sagittal_Angle	Equal variances assumed	.875	.72679	4.60555
	Equal variances not assumed	.875	.72679	4.62322
Axial_Value	Equal variances assumed	.125	-.390373258034371	.253849146577053
	Equal variances not assumed	.122	-.390373258034371	.251829385997262
Coronal_Value	Equal variances assumed	.223	3.08168	2.52592
	Equal variances not assumed	.223	3.08168	2.52375
Total Points	Equal variances assumed	.456	.369	.494
	Equal variances not assumed	.455	.369	.493

Independent Samples Test

		t-test for Equality of Means	
		95% Confidence Interval of the Difference	
		Lower	Upper
Sagittal_Angle	Equal variances assumed	-8.33506	9.78865
	Equal variances not assumed	-8.37093	9.82452
Axial_Value	Equal variances assumed	-.889845949704133	.109099433635391
	Equal variances not assumed	-.885906083948953	.105159567880211
Coronal_Value	Equal variances assumed	-1.88830	8.05166
	Equal variances not assumed	-1.88411	8.04747
Total Points	Equal variances assumed	-.604	1.341
	Equal variances not assumed	-.602	1.339

<u>Nonparametric test:</u> Mann-Whitney Test

Ranks

	Position	N	Mean Rank	Sum of Ranks
Sagittal_Angle	Left	151	160.38	24217.00
	Right	163	154.83	25238.00
	Total	314		
Axial_Class	Left	151	157.26	23746.50
	Right	163	157.72	25708.50
	Total	314		
Coronal_Value	Left	151	165.03	24920.00
	Right	163	150.52	24535.00
	Total	314		
Total Points	Left	151	161.95	24454.00
	Right	163	153.38	25001.00
	Total	314		

Test Statistics[a]

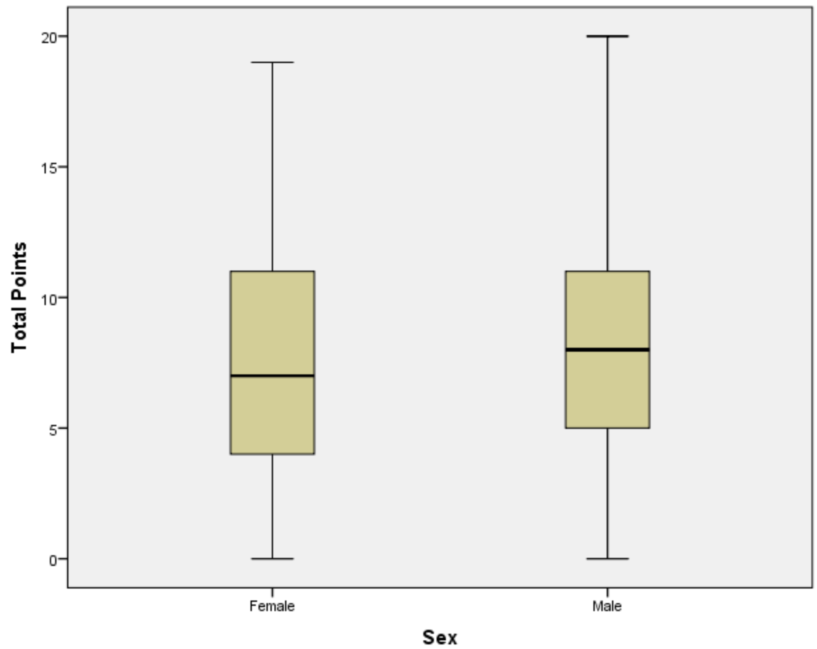
	Sagittal_Angle	Axial_Class	Coronal_Value	Total Points
Mann-Whitney U	11872.000	12270.500	11169.000	11635.000
Wilcoxon W	25238.000	23746.500	24535.000	25001.000
Z	-.541	-.048	-1.415	-.838

Asymp. Sig. (2-tailed)	.589	.962	.157	.402

a. Grouping Variable: Position

Severity:

	Sex			Statistic	Std. Error
Total Points	Female	Mean		7.58	.319
		95% Confidence Interval for Mean	Lower Bound	6.95	
			Upper Bound	8.21	
		5% Trimmed Mean		7.42	
		Median		7.00	
		Variance		17.995	
		Std. Deviation		4.242	
		Minimum		0	
		Maximum		19	
		Range		19	
		Interquartile Range		7	
		Skewness		.438	.183
		Kurtosis		-.455	.363
	Male	Mean		8.35	.405
		95% Confidence Interval for Mean	Lower Bound	7.54	
			Upper Bound	9.15	
		5% Trimmed Mean		8.23	
		Median		8.00	
		Variance		18.008	
		Std. Deviation		4.244	
		Minimum		0	
		Maximum		20	
		Range		20	
		Interquartile Range		6	
		Skewness		.440	.230
		Kurtosis		-.260	.457



Total points is cumulative score that indicates severity.

Percentiles

		Sex	Percentiles 5	10	25	50
Weighted Average(Definition 1)	Total Points	Female	1.90	2.00	4.00	7.00
		Male	2.00	3.00	5.00	8.00
Tukey's Hinges	Total Points	Female			4.00	7.00
		Male			5.00	8.00

Percentiles

		Sex	Percentiles 75	90	95
Weighted Average(Definition 1)	Total Points	Female	11.00	13.20	16.00
		Male	11.00	14.90	16.45
Tukey's Hinges	Total Points	Female	11.00		
		Male	11.00		

Tests of Normality

	Sex	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Total Points	Female	.103	177	.000	.968	177	.000
	Male	.105	110	.004	.976	110	.044

a. Lilliefors Significance Correction

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Primary Canine, Sex, Age, Expander, Appliances[b]	.	Enter

a. Dependent Variable: Total Points

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.255[a]	.065	.048	4.148

a. Predictors: (Constant), Primary Canine, Sex, Age, Expander, Appliances

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	335.763	5	67.153	3.902	.002[b]
	Residual	4818.657	280	17.209		
	Total	5154.420	285			

a. Dependent Variable: Total Points

b. Predictors: (Constant), Primary Canine, Sex, Age, Expander, Appliances

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.659	.579		9.772	.000
	Age	.104	.029	.209	3.550	.000
	Sex	.629	.512	.072	1.228	.221
	Appliances	.760	.576	.079	1.321	.188
	Expander	.470	1.513	.018	.311	.756
	Primary Canine	.394	.504	.046	.781	.435

a. Dependent Variable: Total Points

Table. Multivariable logistic regression examining severity of case
Outcome is Severe compared with mild/moderate cases

Variables	p-value	Odds Ratio	95% C.I.for Odds Ratio	
			Lower	Upper
Male	.666	1.127	.655	1.936
Female	Reference			
Axial Class is Buccal	.001	4.947	1.941	12.606
Axial Classis Palatal	.006	3.767	1.473	9.633
Axial Class is Midalveolar	Reference			
Age (each 1 year increase)	.041	1.032	1.001	1.063
Right side	.718	.907	.532	1.544
Left side	Reference			

Table. Multivariable logistic regression examining severity of case
Outcome is Mild compared with severe/moderate cases

	p-value	Odds Ratio	95% C.I.for Odds Ratio	
			Lower	Upper
Male	.091	.607	.340	1.082
Female	Reference			
Axial Class is Buccal	.000	.209	.104	.421
Axial Classis Palatal	.000	.119	.056	.252
Axial Class is Midalveolar	Reference			
Age (each 1 year increase)	.016	.940	.893	.988
Right side	.055	1.725	.988	3.012
Left side	Reference			