ORIGINAL RESEARCH

Cone-beam Computed Tomography Analysis of the Relationship between the Curve of Spee and the Collum Angle of Mandibular Anterior Teeth

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Abstract

Aims and objectives: To evaluate the correlation between the curve of Spee (COS) of a patient and the Collum angle of mandibular anterior dentition using cone-beam computed tomography (CBCT).

Materials and methods: This cross-sectional study was based on the analysis of 100 CBCTs of patients divided sagittally into two separate subjects. The Collum angles of the mandibular central incisor, mandibular lateral incisor, and the mandibular canine were measured along with the COS of that quadrant using Dolphin Imaging. A multivariate linear regression and Pearson correlation coefficients were conducted to measure the correlation between the COS and the Collum angle of mandibular anterior dentition.

Results: The total number of participants in the cohort was 200 samples out of 100 patients as this was a split mouth study. The mean COS was 2.09 ± 1.239 mm. The mean Collum angle of the mandibular central incisor (L1) was found to be 6.50 ± 3.002 degrees. The mean Collum angle of the mandibular lateral incisor (L2) was 7.19 ± 2.554 degrees and the mean Collum angle of the mandibular canine (L3) was 7.03 ± 2.907 degrees. There was a statistically significant moderate correlation between L1, L2, and L3 and the COS with the Collum angle of the mandibular central incisor most highly correlated to the COS (0.42), followed by the mandibular lateral incisor (0.35) and then the mandibular canine (0.30).

Conclusions: There is a statistically significant low to moderate correlation between the COS and the Collum angles of the mandibular anterior dentition.

Keywords: Collum angle, Cone-beam computed tomography, Curve of Spee.

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Introduction

Differences in dental anatomy affect a tooth's three-dimensional position and ultimately its occlusion. One area of tooth anatomy that is of interest to orthodontists is the crown to root angulation, or the Collum angle.[1] Originally assumed to be zero degrees, it is now known that in most cases, there is a nonzero measurement to this angle.[1,2] As the direction of root formation is fairly susceptible to environmental factors, different malocclusions can lend to different anatomical variations of teeth.[3,4]

This is of concern to orthodontists as this angle is not taken into consideration with the straight-wire appliance, which was originally dictated by Andrews in 1968.[2] Crown variability is almost always accounted for during treatment, while root variability, particularly in the buccal-lingual dimension, is often ignored. The Collum angle of single rooted teeth is of a heightened significance as any deviation from zero can lead to a variable axial force application in certain movements such as intrusion, extrusion, and torqueing.[5] This, in turn, may lead to incidental impingement on the labial or lingual cortical plate and increasing the likelihood of external root resorption.[6,7]

As early as 1980, multiple studies had documented the morphological variation of central incisors among different malocclusions through cephalometric radiographs. There are however limitations to these studies, as the superimposition of three-dimensional structures on top of each other within a two-dimensional image is problematic. With cephalometric radiographs, it is implausible to measure the Collum angle on lateral incisors and canines and difficult to accurately measure the Collum angle of any mandibular anterior tooth. With the advent of cone-beam computed tomography (CBCT), each tooth of interest can now be isolated in a three-dimensional fashion, and the Collum angle can be measured in a more precise manner.

To the best of our knowledge, although there are numerous studies evaluating the Collum angle of central incisors among different malocclusions using cephalometric radiographs, few have been measured using CBCT. Furthermore, no studies have been conducted that factors consider the vertical relationship of the dentition, such as the curve of Spee (COS), and any potential

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relationship to the Collum angle. Therefore, the purpose of this study is to compare the Collum angle of mandibular central and lateral incisors and canines with the COS among different malocclusions.

Materials and Methods

A retrospective, cross-sectional study was conducted to measure the Collum angles (Fig. 1) of pretreatment orthodontic patients and compare them with the COS among different malocclusions. This retrospective study was approved by the Research Ethic Committee of the Institutional Review Board (IRB) at Jacksonville University (IRB #2019-006), where all patients provided written informed consent to have data from their dental records utilized in research.

The sample used in this study consisted of 200 different subjects obtained from 100 different CBCT scans taken from April 2016 to March 2017 at the Jacksonville University. Each patient's scan was split into two to create separate subjects in the sagittal dimension each with its own distinct molar classification and COS depth. All subjects measured had fully erupted, permanent dentition with a full complement of teeth, ensuring a stable COS compared to that of a patient in mixed dentition.[8] Scans of patients were excluded if there was missing dentition or if they were currently under orthodontic treatment or if they had received treatment previously.

CBCT images were obtained in the natural head position using the I-CAT FLX machine at normal settings (field of view 16 cm × 8 cm, voxel size 0.3 mm). The data received from the CBCT werestored as a Digital Imagine and Communications in Medicine (DICOM) format on Jacksonville University password-encrypted servers. Three-dimensional rendering and analysis were performed using Dolphin Imaging (Version 11.95, Patterson Dental Supply, Inc., St. Paul,Minnesota).

Many methods of this study mirror the methods of Ma's study,[9] where each scan then compared to the patient's record on file and pretreatment photos to determine the molar classification to further divide the subjects. For each patient, two subjects were determined by dividing the dentition into right and left sides. Each corresponding side was then grouped into a molar classification, either class 1, 2, or 3 as determined by the American Board of Orthodontics standards for molar classification.[10] All molar classifications that were determined to be "end on" were grouped into their corresponding malocclusion categories. For example, all "end on" class II molar subjects were grouped into the class II molar category.

Using the three-dimensional rendering create by Dolphin Imaging, the "axial slice" tab was utilized to isolate the mandibular arch. The coronal slices were set to have a thickness of 2.0 mm with sagittal slice increments set at 0.5 mm. The axial slice with the best view of the mandibular teeth was selected. Similar to Ma study,[9] the slice will show the mesial and distal contacts of the anterior teeth, the pulp space, and the general triangular anatomic shape of the crown of the anterior tooth.[11] The red indicator line was used to bisect the mesial/distal dimension of each tooth examined to establish the proper horizontal orientation and the midline of the tooth. The proper vertical orientation was found using the "coronal slice" tab. The red indicator line was again used to bisect the mesial/distal dimension of the tooth, depicting the long axis of the tooth. This line typically ran perpendicular to the incisal edge (for incisors) and through the apex of the tooth.

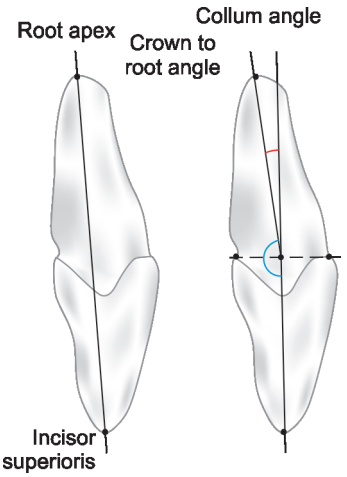

Fig. 1: Crown to root angulation (Collum angle)

Finally, with the tooth centered along the horizontal and vertical axes, the "sagittal slice" tab was selected and the crown to root angle was measured using the "3D angle" feature under the "digitize and measure in 3D" tab. The crown to root angle is measured connecting three points.[9] The first point is "incisor superioris," representing the incisal edge.[11] The second point is called the "bisected cementoenamel junction point" and is the midpoint of the line connecting the facial cementoenamel junction and the lingual cementoenamel junction. The third point is the anatomical root apex. To determine the Collum angle (degrees), the supplementary angle to the crown to root angle, the crown to root angle measurements (x) are subtracted from 180. (Collum angle=180 – x). A positive Collum angle signifies a lingually inclined crown compared to the root axis, whereas a Collum angle of zero denotes a completely straight tooth. Collum angle measurements were obtained for the mandibular central incisors, mandibular lateral incisor, and canine of each subject denoted L1, L2, and L3, respectively.

To measure the COS, the blue indicator line was utilized to lie tangent from the incisal edge of the central incisors to the cusp tip of the distal buccal cusp of the mandibular second molar under the same "sagittal" tab. Using the "2D line" feature under the "digitize and measure in 3D" tab, straight lines were created from the most superior aspect of the buccal cusps of the canines, mandibular first premolars, second premolars, and the mesial buccal cusp of the mandibular first molars to a point perpendicular to the red indicator line and the measurements were determined (mm). The cusp tips were found by scanning the sagittal slices of the "4-equal-slices-volume layout" tab while manipulating in the axial slice display's red indicator line, holding the coronal display constant. These values were then averaged to determine the COS of that subject.[12]

Statistical Analysis

All recorded data were summarized using descriptive statistics using number, mean, standard deviation (SD), median, minimum, and maximum. Pearson correlation coefficients were calculated to measure the association between the COS of a patient and the Collum angle of mandibular anterior dentition. Tests for the absence of correlation were performed using z-test a 5% level. Multivariate linear regression was conducted on COS using molar classification and Collum angles as predictor variables. All analyses

were conducted using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina).

Results

The total number of participants in the cohort was 200 samples out of 100 patients as this was a split-mouth study. Of those subjects, 62.5% were class I molar, 22.5% were class II, and 15% class III. Out of the total number of subjects, the mean COS was 2.09 ± 1.239 mm. The COS of the subjects ranged from 0.00 mm, otherwise known as a flat COS to as deep as 5.00 mm. Out of the 200 subjects, one mandibular lateral incisor and two canines were omitted from the study as their Collum angle values were extreme due to atypical anatomy.

Table 1 demonstrates the descriptive statistics for the Collum angle measurements for mandibular central incisor (L1), mandibular lateral incisor (L2), and mandibular canine (L3), respectively, regardless of molar classifications. The mean Collum angle of L1 was found to be 6.50 ± 3.002 degrees. The mean of L2 was 7.19 ± 2.554 degrees and the mean of L3 was 7.03 ± 2.907 degrees.

Table 2 divides the groupings further and examines the Collum angles of L1, L2, and L3 as well as the COS by molar class. The greatest variation between the mean Collum angle between molar classes was observed in the L1 category. The L1s of class III subjects observed the lowest mean Collum angle at 5.80 degrees, followed by the class 1 subjects at 6.26 degrees. Class II subjects showed the greatest mean Collum angle at 7.61 degrees. This was the highest mean Collum angle measured among the entire study. The mean Collum angles of the mandibular lateral incisors followed a similar pattern in that the mean Collum angle of class III subjects was the smallest (6.35 degrees) followed by the class 1 subjects (7.26 degrees) and then the class II subjects (7.57 degrees). This pattern was not observed in the L3 subjects as the class 1 subjects exhibited the highest Collum angle (7.30 degrees) followed by the class II subjects (6.89 degrees) and then the class III subjects (6.13 degrees).

Table 2 also provides a breakdown of COS per molar class. Class II subjects demonstrated on average the deepest COS (2.68 degrees) followed by the class 1 subjects (2.04 degrees) and then class III subjects (1.41 degrees).

The correlations between the Collum angles of L1, L2, and L3 and the COS are presented in Figure 2. The COS was positively correlated with the three Collum angles. The correlation between the COS and L1 was the highest at 42%, followed by L2 with 35%, and L3 at 30%.

A multivariate linear regression was performed on the COS using molar class and Collum angles as predictors. The estimated regression coefficients of the predictors are presented in Table 3 along with the *t*-test results to test whether the predictor is statistically significantly associated with the COS. The results showed that molar class was not a significant predictor of COS. The COS, however, was a statistically significant predictor of the Collum angle of L1, L2, and L3 to various correlations. An increase in the COS of by 0.5 mm theoretically translated into an increase of the Collum angle of L1 by 3.78 degrees, whereas the same increase in the COS only translated into an increase of L3's Collum angle by 0.14 degrees. An increase of all Collum angles by 5 degrees translates into an increase of COS by 5× (0.132 + 0.101 + 0.070) = 1.51 mm.

Although the results showed the presence of a correlation between COS and the Collum angles of L1, L2, and L3, the intensity of this correlation, according to the Pearson correlation coefficient, is low to moderate (correlation is below 50%). The L1 Collum angle the highest correlation to the COS at 0.42 and the L3 Collum angle at the lowest correlation at 0.30. The Collum angles combined explained only 26% (adjusted R-square) of the total variability of the COS.

Table 1: Descriptive statistics

Variables	*TotalN = 200*
Molar class [*n*(%)]	
Class I	125 (62.5)
Class II	45 (22.5)
Class III	30 (15.0)
Total	200
L1 Collum angle (degrees)	
n	200
Mean (SD)	6.50 (3.003)
Median	6.15
Min–Max	0.20–15.60
N/R	0
Total (*N*)	200
L2 Collum angle (degrees)	
n	199
Mean (SD)	7.19 (2.554)
Median	7.20
Min–Max	0.70–14.80
N/R	1
Total (*N*)	200
L3 Collum angle (degrees)	
n	198
Mean (SD)	7.03 (2.907)
Median	6.80
Min–Max	0.90–19.40
N/R	2
Total (*N*)	200
Curve of Spee (mm)	
n	200
Mean (SD)	2.09 (1.239)
Median	2.10
Min–Max	0.00–5.00
N/R	0
Total (*N*)	200

SD, standard deviation; Min, minimum; Max = maximum; Total: number of observations, % = 100 × (*n*/Total)

Discussion

The results of this study indicate that there is a statistically significant correlation between the COS and the Collum angle of mandibular anterior teeth. There is a higher correlation between the COS and the Collum angle of the mandibular central incisor than the lateral incisor and a higher correlation between the COS of the lateral incisor than the canine. This can be perhaps best explained by the position of each tooth along the dental arch, particularly in the anterior–posterior dimension, and the corresponding soft tissue pressures that are exhibited. As demonstrated by Thüerand Ingervall,[13] there is more force exhibited by the lower lip at the position of the mandibular central incisors compared to the

Table 2: Descriptive statistics by molar class

Variables	*Class I*	*Class II*	*Class III*	*Total*
L1 Collum angle (degrees)				
n	125	45	30	200
Mean (SD)	6.26 (2.899)	7.61 (3.305)	5.80 (2.593)	6.50 (3.003)
Median	5.90	7.10	5.95	6.15
Min–Max	0.70–15.60	1.00–14.00	0.20–10.80	0.20–15.60
N/R	0	0	0	0
L2 Collum angle (degrees)				
n	124	45	30	199
Mean (SD)	7.26 (2.575)	7.57 (2.560)	6.35 (2.342)	7.19 (2.554)
Median	7.15	7.40	6.95	7.20
Min–Max	2.10–14.80	0.70–14.30	1.20–9.80	0.70–14.80
N/R	1	0	0	1
L3 Collum angle (degrees)				
n	123	45	30	198
Mean (SD)	7.30 (2.949)	6.89 (1.977)	6.13 (3.705)	7.03 (2.907)
Median	7.50	6.80	6.05	6.80
Min–Max	1.00–13.60	2.20–11.50	0.90–19.40	0.90–19.40
N/R	2	0	0	2
Curve of Spee (mm)				
n	125	45	30	200
Mean (SD)	2.04 (1.233)	2.68 (0.945)	1.41 (1.283)	2.09 (1.239)
Median	2.10	2.70	1.40	2.10
Min–Max	0.00–4.80	0.90–5.00	0.00–4.80	0.00–5.00
N/R	0	0	0	0

SD, standard deviation; Min, minimum, Max, maximum.

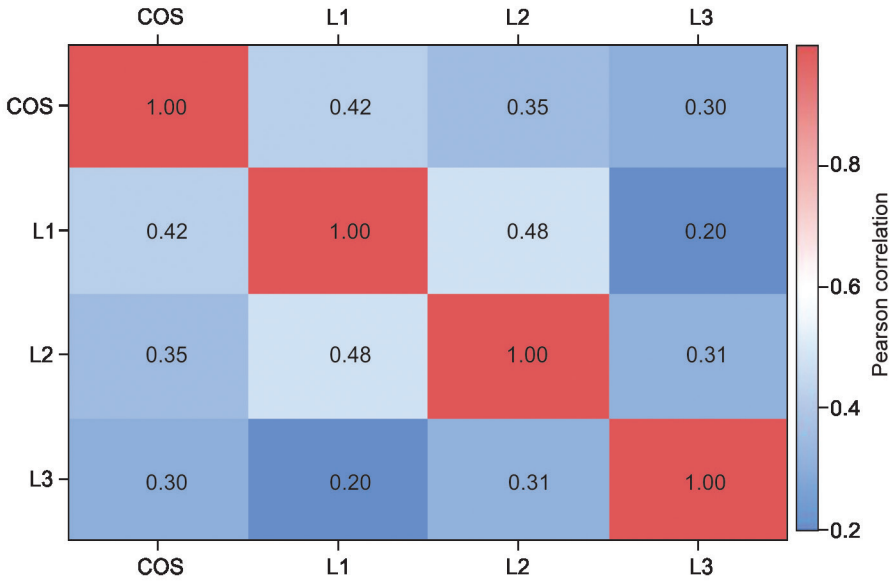

Fig. 2: Correlation between Collum angles of mandibular anterior teeth and curve of Spee. COS indicates curve of Spee; L1, mandibular central incisor; L2, mandibular lateral incisor; L3, mandibular canine

mandibular lateral incisors and canines.[14] As the curve deepens more through eruption and relative extrusion of the incisors, they could become more susceptible to the pressures of the lip as the root finishes its development. These correlations are of low to moderate values, suggesting there must be other factors that determine the Collum angles and not just the COS.

The decreased mean Collum angle of the mandibular central incisor (6.50 degrees) compared to that lateral incisor (7.19 degrees) and canine (7.02 degrees) was similar to Ma's 2016 study[9] and also Germane et al. study[15] of tooth morphology of extracted teeth. This study, however, exhibited a different pattern in that the mandibular lateral incisor exhibited a greater Collum angle than the mandibular

Table 3: Linear regression of curve of Spee (mm) on molar class and Collum angles L1, L2, and L3 (in degrees)

Regression coefficient estimates				
Effect	*Estimate*	*StdErr*	*t value*	*p value*
Intercept	0.186	0.3238	0.58	0.5654
L1	0.132	0.0287	4.61	<0.0001
L2	0.101	0.0359	2.82	0.0053
L3	0.070	0.0276	2.55	0.0117
Class	−0.096	0.1026	−0.94	0.3481

DF: degree of freedom

canine. The Collum angle of the lateral incisor in this study was 7.19 degrees compared to 3.8 degrees in Germane's study and 6.49 degrees in Ma's study. The Collum angle of the canine in Germane's study was 4.0 degrees, in Ma's study was 7.82 degrees, and in this study was 7.02 degrees.

Breaking the subjects down by molar classification, the greatest difference in the crown to root axis was seen in subjects with class II molar classification, followed by subjects with class 1 molar classification and finally class III molar classification. The increased Collum angle in the class II group could be explained by several factors. Once again, it has been studied by the likes of Backlund and others that those exhibiting a class II molar relationship, particularly those of class II subdivision II relationship, exhibit a more hypertonic lower lip, affecting the Collum angle of the maxillary incisors.[14,16,17] This study demonstrates that the mandibular incisors can be affected as well.

Though the Collum angle of mandibular teeth has been studies previously, this is only the second study of its kind using CBCT technology. By using this technique, we have eliminated any superimposition effects that a two-dimensional image, particularly a lateral cephalogram, suffers while evaluating a single tooth. We have also created a way to orient each particular tooth down its long axis in a three-dimensional manner. Furthermore, this is the only study to date to have evaluated the Collum angle and compare it to the vertical orientation of the dentition as determined by the COS.

The clinical implications of this study are multifold. As this study adds to the long list of others that have studied the Collum angle, it is now widely understood that Andrews incorrectly assumed that the Collum angle of all teeth was zero. Additionally, it is understood that there is variability among Collum angle between teeth and between different malocclusions that will factor into orthodontic treatment. The greater the Collum angle of a tooth is from zero, the higher risk the root could contact the lingual cortical plate as the full prescription of the bracket is met. As this happens there is an increased risk of root resorption, in extreme cases, the cortical plate could be perforated.[3] This risk could be amplified in class II molar patients, a subgroup with a historically increased L1, L2 Collum angle, where a common mechanic is the proclination of the mandibular incisors in order decrease overjet.[4] This proclination and uncontrolled tipping could exacerbate this problem.

There are other mechanics that could induce varied unwanted forces on these teeth depending on the Collum angle. Heravi et al determined that maxillary central incisors' periodontal ligament experienced more stress in the presence of retraction forces when the Collum angle is larger, suggesting that there could be an increased risk of resorption.[18] The same study also suggested that intrusion forces experienced by teeth with larger Collum angles are actually smaller than those experienced with Collum angles closer to zero. In situations where there is a deep bite at the beginning of treatment, and typically a larger COS, the incisors must be intruded a greater distance to establish an ideal occlusion, where the degree of the Collum angle could become a factor.[19] The Collum angle of anterior teeth can no longer be ignored when treatment planning, particularly in those cases where the aforementioned mechanics exist.

Conclusion

- There is a statistically significant relationship between the COS and the Collum angles of the mandibular anterior dentition. This relationship is of low to moderate correlation. The COS accounts for some of the variability of the Collum angles.
- There is not a statistically significant difference between molar classification and the COS. More variables need to be studied in order to understand the variation in Collum angles among the mandibular anterior dentition.

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