Maxillary central incisor crown-root relationships in class I normal occlusions and class III open and deep malocclusions

Jessica Kay Fuller

University of Iowa

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MAXILLARY CENTRAL INCISOR CROWN-ROOT RELATIONSHIPS IN CLASS I NORMAL OCCLUSIONS AND
CLASS III OPEN AND DEEP MALOCCLUSIONS.

by

Jessica Kay Fuller

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Orthodontics
in the Graduate College of
The University of Iowa

May 2015

Thesis Supervisor: Professor Robert N. Staley
This is to certify that the Master's thesis of

Jessica Kay Fuller

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Orthodontics at the May 2015 graduation.

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I also wish to express my gratitude to Dr. Tom Southard and the rest of the faculty here at the University of Iowa for giving me the opportunity to further my education and pursue a career in orthodontics.

Lastly, I would like to thank my husband Ben and my children, Natalie, William and my baby girl arriving soon, for bringing me love and happiness beyond what I ever thought possible.
ABSTRACT

Introduction: The purposes of this thesis were several: (1) to examine a new crown-to-root angle based on anatomic points, the labial crown-root angle (LCRA), that was proposed in a recent University of Iowa thesis by Bauer, T.J. (2014) and correlate it with the collum angle (CA) values for Class I normal occlusions and Class III malocclusions; (2) to establish mean values for CA and LCRA for Class I normal occlusions and Class III open and deep bite malocclusions and statistically compare the groups; (3) to compare the significance of the correlation between overbite measures and CA and LCRA in the Class III sample. Only one study addressed the increased CA in Class III malocclusions however, the study did not include a normal occlusion control sample. Methods: 46 Class I normal samples, 20 Class III open bite samples and 22 Class III deep bite samples who met the inclusion criteria were measured cephalometrically. Relevant landmarks were placed, analyzed for reliability, and recorded for the measurements of interest. Results: A strong increasing correlation was found between CA and LCRA for all samples (Pearson’s correlation coefficient = 0.82, p < .0001). The mean CA for the Class III deep bite group (9.32±4.46) was significantly different from the Class I normal core (3.38±1.70), Class I expanded (3.60±1.94) and Class III open bite (5.24±3.99) groups (ANOVA). The mean LCRA for the Class III deep bite group (39.67±5.64) was also significantly different from Class I normal core (31.97±4.25), Class I expanded (33.53±5.65) and Class III open bite (35.55±5.65) groups (ANOVA). There was no significant correlation between CA and overbite within Class III open (p=0.8029) and Class III deep bite groups (p=0.2089) or LCRA and overbite within Class III open (p=0.7529) and Class III deep bite groups (p=0.1864). Conclusions: LCRA and CA were highly correlated in Class III patients. Patients with Class III deep bites had statistically higher means for CA and LCRA than patients with Class I normal occlusions and Class III open bite malocclusions. There was no significant correlation between the measures for overbite and either CA or LCRA values in Class III patients.
Introduction: The purpose of this study were several: (1) examine a new measurement for the angle of the maxillary central incisor called labial crown-root angle (LCRA) and correlate it with the accepted existing measurement, collum angle (CA), for different types of dental malocclusions; (2) establish average values for CA and LCRA for different types of dental malocclusions and compare them; (3) compare the amount of overbite and values for CA and LCRA for different dental malocclusions.

Methods: 46 Class I samples, 20 Class III open bite samples and 22 Class III deep bite samples who met the criteria were examined using x-rays. Results: A strong correlation was found between CA and LCRA for all samples. The mean CA and LCRA for the Class III deep bite group was significantly different from the Class I normal core, Class I expanded and Class III open bite groups. There was no significant correlation between CA or LCRA and overbite within Class III open and Class III deep bite groups.

Conclusions: LCRA and CA were highly correlated in Class III patients. Patients with Class III deep bites had statistically higher average CA and LCRA compared to Class I normal occlusions and Class III open bite malocclusions. There was no significant correlation between the measures for overbite and either CA or LCRA values in Class III patients. This information will help orthodontists identify and better treat patients with higher CA and LCRA values. We recommend LCRA as a better method of measuring the crown-root angle.
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INTRODUCTION

Concern for root resorption is commonplace in the clinical practice of orthodontics. A common reason cited for root resorption is vertical movement of teeth by both intrusion and extrusion (Parkers and Harris 1998). Other reasons for resorption of anterior teeth include root torqueing or translation into the palatal cortex (Kaley and Phillips 1991, Parkers and Harris 1998). Root angulation in relation to the crown, or the “collum angle”, is something that can increase an individual’s risk for root resorption when intruding, extruding and torqueing teeth.

Modern orthodontics is largely based on the use of the straight wire edge-wise appliance described by Andrews in 1968. This design has simplified treatment by allowing for fewer wire bends, especially in the finishing stages of orthodontics. One complexity in orthodontic treatment is to account for individual variation in crown and root form while using the straight edge-wise appliance. While repositioning of brackets can help with crown variation, variation in the collum angle (CA), which is in the buccal lingual dimension, is unable to be addressed by bracket positioning. Therefore, there is not a predictable way to prevent the likelihood of torqueing a root into the boney cortex in cases with large CAs. Several studies have demonstrated there is an increased incidence of CA particularly in Class II Division II malocclusions and Class III malocclusions (Bryant 1984, Delivanis 1980, Harris 1993). This makes thorough treatment planning in these cases all the more important since standard prescriptions and even cephalometric tracings assume the CA of teeth to be zero. Most orthodontists will identify root resorption on final pantomograph radiographs but it is unlikely many will associate the resorption with the presence of a CA. When one looks at the literature for studies of orthodontic root resorption, to my knowledge, we rarely have seen the presence of a CA investigated as a causal factor which may account for decreased public awareness on the subject.

Another reason for decreased awareness of the CA may stem from the difficulty to reliably measure this angle on cephalometric radiographs. While cephalometric measurements are currently
the standard in treatment planning, it is generally accepted that there are errors in landmark identification due to superimposition of multiple structures. Additionally, there is error in constructed landmarks from bisecting and tangent lines or interpretation of points on a curve (Baumrind and Frantz 1971). CA is just one example of a measure that is difficult to obtain based on current cephalometric tracing aids utilized to date in clinical practice. The measurement consists of three points: the central incisor incisal edge, the bisection point of the labial and lingual cementoenamel junctions, and the root apex. The difficulty in identifying the bisecting point of the labial and lingual cementoenamel junctions is properly identifying the lingual CEJ due to superimposition of teeth in this region.

In an effort to decrease error in the measurement of the CA, a new angular measurement was recently proposed in a thesis by T.J. Bauer et al (2014), called “labial crown root angle” (LCRA). This study found a high correlation between LCRA and CA. The advantage to this measurement is that it consists of easily identifiable points on cephalometric radiographs: central incisor incisal edge, central incisor labial cementoenamel junction, and central incisor root apex.

The current study has several specific aims. First, the study will reexamine the relationship between LCRA and CA to verify LCRA can be a reliable altemative measurement to CA alone. Second, it will establish a mean value for maxillary incisor CA and LCRA for Class I normal occlusion and two groups of Class III malocclusion groups separated on the basis of being an open bite or deep bite subgroup. Next the study will look to see if there are any differences between Class III subjects and Class I normal subjects and will compare both the Class III deep and open bite subjects to analyze differences. There is currently only one study that addresses the increased CA in Class III malocclusions postulating that deflection of the upper incisor crown by the lower dental arch during tooth development causes “bending” of the crown-root angle (Harris 1993). If this is the case, then it can be theorized that there should be a difference between the CA and LCRA for Class III deep bite and class III open bite subjects.
Third and lastly, this study will test to see if there is any correlation between percentage overbite and CA or LCRA.
LITERATURE REVIEW

One aspect that occasionally comes up in orthodontics is the angle of the crown to the root, or the “collum angle.” While it may not be routinely included as an influential factor in treatment planning, the presence of a large CA might limit the correct tracing of the longitudinal axis of the central incisor (Carlsson and Ronnerman, 1973). This could lead to inappropriate diagnosis of the upper incisor crown-root anatomy in these cases which could increase the risk of root resorption of these teeth.

External apical root resorption (EARR) is a common iatrogenic problem as a result of orthodontic treatment. Literature has long suggested that intrusive and extensive root movements can substantially increases the risk of EARR (Parker and Harris 1998). In fact, it has been suggested that up to 3mm of root resorption occurs from orthodontic treatment at a frequency of 10-20% which is quite alarming (Hollender et al 1980, Levender et al 1988). In a study by Parker and Harris (1998), 110 adolescents with similar malocclusions (Class I crowded) and treatment plans (four bicuspid extraction) were examined. The aim of the study was to examine direction of orthodontic movements associated with EARR of the maxillary central incisor. Three treatment techniques were examined: Tweed standard edgewise, Begg light wire, and Roth prescription. The study found no statistical difference between techniques and gender. They found tooth movements were highly predictive and could explain up to 90% of root resorption variation. The strongest predictor of EARR was incisor intrusion with lingual root torque. In contrast, bodily retraction, extrusion and lingual crown tip had minimal effect (Parker and Harris 1998). This could have tremendous implications for incisors with increased CA as the likelihood of increasing proximity to the palatal cortex is exacerbated with any torque and apical or incisal vertical movement.

It has been reported that the size and shape of teeth appear to be under “moderately strong” genetic control. However, while crown morphology appears to be pretty consistent, root dimensions are not strongly correlated to crown form or size and appear to be more under environmental influence (Harris 1993). While typically the root angulation in relation to the crown is assumed to be zero, several
studies have shown a range of values and a few of these studies actually categorize teeth into different malocclusion classes. In a study of 600 extracted teeth by Germene et al (1989), researchers looked at mean facial contour values for homologous teeth from different individuals, mean faciolingual contours when viewed from the incisal/occlusal, and mean CA. Interestingly, they did not find any of the mean CAs for different teeth to be significantly different from zero, but the standard deviation was ±3 degrees showing there was a range of CA values. Since the type of malocclusions represented in this sample is unknown, this was not necessarily a representation of all teeth since many studies have shown that different malocclusion types have an increased incidence of higher CAs.

Types of occlusion that have shown to have an increased collum angles include Class II Division II and Class III malocclusions. In a study by Delivanis and Kufinex (1980), they looked at fifty-three Class II Division II patients and fifty-three control patients. The control group was noted to be made up of classifications other than Class II Division II. The authors found that the mean CA for Class II Division II patients was 6.14 ± 5.14 degrees, compared to the control value of 1.52 ± 4.36 degrees. Limitations of the study included the absence of a Class I normal control group.

In another study by Bryant et al (1984), 98 extracted teeth and 100 cephalometric radiographs were evaluated for the presence of crown-root angulation in the labiolingual direction. Both teeth and radiographs were separated by Angle classification. Results showed a wide variation in crown-root angulation. The mean crown-root angle for Class II Division II malocclusions (175.18 ± 5.13 degrees) differed significantly from that of Class II Division I (179.40 ± 4.02 degrees) and Class III malocclusions (178.60 ± 4.70 degrees).

In a third study by Harris et al (1993), cephalometric samples of central incisors were examined for Class I, Class II, and Class III malocclusions. Again no Class I normal sample was measured. Harris et al (1993) reported mean CA values for the different Angle malocclusion classifications to determine if CA predisposed them to root resorption, and found cephalometric predictors of increased crown to root
angulation. CAs for Class I, Class II and Class III malocclusions were found to be 6.1 degrees, 5.6 degrees, and 12 degrees. Class I and Class II values were found not to be statistically different, but Class III CA values were found to be significantly different. As far as predisposition to root resorption, Harris et al found that neither molar class nor CA were correlated to resorption. For cephalometric predictors of increased CA, they found that a smaller U1 to Frankfort horizontal angle was a predictor. An important finding from Harris et al is that this is the only study that has reported the degrees of CA in Class III malocclusions. In the discussion, the authors speculated that the increased CA in Class III deep bite malocclusions may be associated with the lingual deflection of the upper incisor crown by the lower dental arch during tooth development, resulting in “bending” of the crown-root angle (Harris, 1993). If the roots are more susceptible to environmental influences than the crowns during growth, it is possible that this biologic responsiveness of the root of the upper central incisor could explain the association between CA and deep overbite. Our current study aims to investigate this hypothesis proposed by Harris et al.

The presence of increased collum angles has important implications when it comes to the use of edgewise appliances. In 1928, Edward H Angle introduced the edgewise appliance where final tooth position was achieved from ligation of appropriately adjusted rectangular arch wires into rectangular bracket slots. Later, in 1968 Andrews went a step further to advocate a “straight wire” concept which was meant to limit the amount of bends necessary in the arch wire and simplify treatment. While this concept has simplified treatment, one disadvantage is that the specific bracket prescriptions for the teeth assume tooth morphology is uniform and bracket placement is ideal each time. If in fact several types of malocclusions, including Class II Division II and Class III malocclusions, have higher incidences of increased CA, special care should be used when using standardized prescription brackets. It is common in Class II Division II malocclusions to even use “high torque” incisor brackets to aid in proclining the incisors which, with the presence of a CA, could potentially drive the roots into the palatal cortex. For
Class III malocclusions it is often also necessary to procline upper incisors to correct or prevent anterior cross bite. This is one more example of a case where risk of root resorption could be increased.
OBJECTIVES OF THIS STUDY

The objectives of this research project were to test the following null hypotheses:

1. There is no correlation between CA and LCRA.

2. CA and LCRA from subjects with Class III deep bite malocclusions are not different from subjects with Class I normal occlusions or with Class III open bite malocclusions.

3. There is no correlation between the amount of overbite and CA or LCRA among the subjects with Class III open and deep bite malocclusions.
MATERIALS AND METHODS

Sample Selection

This study was designed as a retrospective cross-sectional study to measure CA, LCRA, and overbite of maxillary central incisors for patients with Class I “normal” occlusions and Class III open and deep malocclusions. The Class I “normal” sample was taken from the Iowa Growth Study by Meredith and Knott (1973). This normal sample was based on criteria of having a class I molar relationship and mild crowding/spacing. For this specific study, the normal sample was further subdivided based on amount of crowding/spacing. Subjects with ≤1mm of crowding or spacing were designated as part of the Class I normal core group. Subjects with 2-4mm of crowding/spacing were called the Class I normal expanded group. Subjects who had undergone orthodontic treatment were excluded as this would affect our overbite measurement, and subjects whose cephalometric radiographs were of poor quality were also excluded as they would affect accuracy of measurements.

The Iowa Growth Study was started in 1946 by Howard V Meredith and L.B. Higley (Meredeth and Knott, 1973). There were a total of 130 subjects, ninety-seven percent of whom were of northwestern European ancestry and three percent of other European decent. Casts were taken twice yearly until age 12 and once yearly until age 17. After this time, casts were made periodically based on continued participation of the volunteers. To fulfill all the inclusion criteria, participants had to be in the Iowa City local area, enrollment was based on a volunteer basis, and all subjects were normal physically and had normal cephalic and dento-facial features (Meredith and Knott, 1973).

The Class III open and deep bite malocclusion subjects used in the study were obtained from a list of patients maintained in the University of Iowa Department of Orthodontics that are used for studies by residents. After review of the available cephalometric radiographs, 20 open bite (14 males and 6 females) and 22 deep bite (15 males and 7 females) patients were selected based on having high enough quality radiographs that required landmarks could be easily identified. All Class III samples met
the American Board of Orthodontics criteria for Class III malocclusion. All subjects were minimally Class III by 3mm bilaterally or Class III by 6mm unilaterally. Open bite and deep bite was determined by measurement of percentage of overbite between maxillary and mandibular incisal edges. End to end occlusion was included in the open bite group and was arbitrarily set at a value of -0.01% to aid statistical analysis.

**Cephalometric Data**

Lateral cephalometric radiographs from the Iowa Growth Study were scanned, digitized, and loaded into dolphin (version 11.5) for landmark identification and measurement. Scanning and image formatting was completed by the University of Iowa College of Dentistry Educational Media Department. Since all measurements used in the study was angular or based on percentage, no calibration of images were necessary. Class III radiographs were already in dolphin imaging so no uploading of radiographs was necessary.

A customized analysis was created for this specific study. Since there is no measure of CA and LCRA, landmark labels typically used for other measurement purposes were re-utilized to give the measurements required. Inclusion criteria to the study included proper image quality and clarity. The most common reasons for excluding radiographs included poor image quality due to darkness or contrast or poor visualization of necessary landmarks due to superimposition of other structures in the same area. Stringent screening was thought necessary to maximize observer agreement and ensure accuracy of measurements.

Measurements for all subjects were made by the primary observer (J.F.) and entered into an Excel spreadsheet. Twenty subjects, five from each of the four groups, Class I normal core, Class I normal expanded, Class III open bite, and Class III deep bite, were selected randomly by the statistician and measured again by J.F. at least twenty-four hours from her first measurement and by a second observer (K.D.), a dental student, who was trained on how to identify relevant landmarks and use the
customized analysis created in Dolphin. These additional measurements were recorded into separate
 spreadsheets which were later combined into one master spreadsheet by J.F.  The master spreadsheet
was reviewed for any obvious measurement errors, typographical errors and omissions first, and then
submitted to the statistician for the evaluation of the intra- and inter-rater reliability of measurements.

**Description of Measurements**

CA is traditionally measured from three points on the most anterior maxillary central central
incisor. These points include the undamaged incisal edge termed incisor superius (IS), a constructed
bisection point midway between the labial (ICEJ) and facial (fCEJ) cemento-enamel junctions, and the
anatomical root apex termed upper incisor apical (UIA). The CA is a supplement of this angle found from
the mathematical equation, 180 degrees minus the angle (Rakosi 1982). To further interpret this angle it
is important to understand a straight tooth would have a CA of zero, a lingual inclined tooth a positive
CA, and buccal inclined tooth a negative CA. Figure 1 illistrates points used in this study for CA.

The LCRA is a new angle first proposed by Bauer et al in a Thesis from 2014. This measure
consists of three points: UIA, fCEJ and IS. It also is a construct from the mathematical equation, 180
degrees minus the angle (Bauer 2014). The main advantage of this measurement is that the three
points required are more easily identifiable on a lateral cephalometric radiograph than the ones to
define CA. Limitations to the measurement would depend on how well it correlates with CA since the
measure is ultimately attempting to replace CA as an alternative measure for crown-to-root angulation.
LCRA is illustrated in figure 2.

Overbite is calculated from three points: IS, the most anterior mandibular incisor undamaged
incisor edge (IIS), and the mandibular incisor facial cemento-enamel junction (IfCEJ). Deep bite
occlusion would have a positive percentage and open bite occlusion a negative percentage. Cases that
have end to end occlusion were set arbitrarily at -0.01% for ease of statistical analysis. Figures 3 and 4
depict examples of open and deep bite cases.
Figure 1. The collum angle
Figure 2. The labial crown-root angle
Figure 3. Class III open bite overbite measurement

$$(-)^\% = \frac{X_1 - X}{X} 	imes 100$$
Figure 4. Class III deep bite overbite measurement

\[(+\%) = \frac{X_1 - X}{X} \times 100\]
Measurement Reliability

Twenty subjects were randomly selected, and duplicate measurements of CA, LCRA and overbite from each subject were made by the same observer or the two observers. Intraclass correlation coefficients were computed as a measure of reliability of measurements. Table 1 shows the approximate guide for interpreting agreement between the two measurements that correspond to an intraclass correlation coefficient. In addition, a paired-sample t-test and Wilcoxon signed-rank test (a non-parametric analog of a paired-samples t-test) were used to detect the significant differences between duplicated measurements by J.F. or by the two observers, J.F. and K.D.

<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>0.00-0.20</td>
<td>Weak correlation</td>
</tr>
<tr>
<td>0.20-0.40</td>
<td>Fair correlation</td>
</tr>
<tr>
<td>0.40-0.60</td>
<td>Moderate correlation</td>
</tr>
<tr>
<td>0.60-0.80</td>
<td>Good correlation</td>
</tr>
<tr>
<td>0.80-1.00</td>
<td>Strong correlation</td>
</tr>
<tr>
<td>1.00</td>
<td>Perfect correlation</td>
</tr>
</tbody>
</table>

Table 1. Interpretation of intraclass correlation coefficients
Intra-Observer Agreement

Intra-observer agreement of CA measurements were evaluated to assess agreement between two separate measurements made by J.F. made at least 24 hours apart from one another. Finding showed that overall there was very strong evidence that the intraclass correlation differed from zero (P<0.0001), and a correlation coefficient of 0.99 indicated strong agreement between the two measurements. Additionally, by a paired-sample t-test, no significant difference was found between the two measurements for J.F. (p=0.8911). The overall mean difference between the first and second measurements was 0.02 ± 0.64 (Table 2).

Similarly for LCRA, there was very strong evidence that intraclass correlation differed from zero (P<0.0001), with a correlation coefficient also of 0.99 indicating strong agreement between the first and second measurements made by J.F. By the paired-sample t-test, no significant difference was observed between the two measurements (p=0.1205). The overall mean difference between the first and second measurements was -0.21±0.59 (Table 2).

Lastly, intra-observer agreement for overbite was evaluated and there was strong evidence that the intraclass correlation differed from zero (P<0.0001). The correlation coefficient was 0.99 indicating strong agreement. Moreover, no significant difference was found between the first and second measurements of overbite made by J.F. (p=0.8830, a paired-sample t-test) using a paired-sample t-test. The overall mean difference between the two measurements was -0.02 ± 0.75 (Table 2).
### Table 2. Intra-observer measurement agreement for CA, LCRA, and overbite

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1st CA</strong></td>
<td>20</td>
<td>5.63</td>
<td>3.82</td>
<td>2.50</td>
<td>15.20</td>
<td>4.25</td>
<td></td>
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<tr>
<td><strong>2nd CA</strong></td>
<td>20</td>
<td>5.61</td>
<td>3.68</td>
<td>1.80</td>
<td>14.40</td>
<td>4.35</td>
<td></td>
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<tr>
<td><strong>CA Difference between 1st and 2nd Measurements</strong></td>
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<td>0.02</td>
<td>0.64</td>
<td>-1.10</td>
<td>1.00</td>
<td>0.20</td>
<td>0.8911</td>
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<tr>
<td><strong>1st LCRA</strong></td>
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<td>36.64</td>
<td>6.82</td>
<td>26.50</td>
<td>52.00</td>
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<tr>
<td><strong>2nd LCRA</strong></td>
<td>20</td>
<td>26.85</td>
<td>6.85</td>
<td>26.20</td>
<td>52.20</td>
<td>36.15</td>
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<tr>
<td><strong>LCRA Difference between 1st and 2nd Measurements</strong></td>
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<td>-0.21</td>
<td>0.59</td>
<td>-1.10</td>
<td>1.20</td>
<td>-0.25</td>
<td>0.1205</td>
</tr>
<tr>
<td><strong>1st Overbite</strong></td>
<td>20</td>
<td>18.82</td>
<td>33.75</td>
<td>-67.10</td>
<td>56.50</td>
<td>28.80</td>
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<tr>
<td><strong>2nd Overbite</strong></td>
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<td>18.84</td>
<td>33.80</td>
<td>-68.00</td>
<td>56.30</td>
<td>28.80</td>
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<tr>
<td><strong>Overbite Difference between 1st and 2nd Measurements</strong></td>
<td>20</td>
<td>-0.02</td>
<td>0.75</td>
<td>-1.60</td>
<td>1.00</td>
<td>0.15</td>
<td>0.8830</td>
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</table>

**Inter-Observer Agreement**

Since the primary observer J.F. made two measures of each subject for each variable, an average of the two measurements was used to compare to measurements of the second observer K.D for the evaluation of the inter-observer agreement. An intraclass correlation coefficient was computed to evaluate the inter-observer agreement of CA measurements between two separate measurements made by J. F. and K.D. Finding showed that overall there was very strong evidence that intraclass
correlation differed from zero (P<0.0001), and a correlation coefficient of 0.99 indicated strong agreement between the two measurers. Additionally, by a paired sample t-test, no significant difference was found between the two measurement of J. F. and K.D. (p=0.6398). The overall mean difference between the two measurers was -0.06 ± 0.61 (Table 3).

Similarly for LCRA, there was very strong evidence that intraclass correlation differed from zero (P<0.0001), with a correlation coefficient of 0.98 indicating strong agreement between the two measurements made by J.F. and K.D. By the paired t-test, no significant difference was observed between the two measurements (p=0.8422). The overall mean difference between the two observers was 0.06 ± 1.27 (Table 2).

Lastly, inter-observed agreement for overbite was evaluated and there was strong evidence that the intraclass correlation differed from zero (P<0.0001). The correlation coefficient was 0.99 indicating strong agreement between the two measurements made by the two observers. Moreover, no significant difference was found between the two measurements of overbite made by J.F. and K.D. (p=0.5286) using a paired-sample t-test. The overall mean difference between the two measurers was -0.24 ± 1.69 (Table 3).
<table>
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</tr>
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<td>-4.00</td>
<td>3.45</td>
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<td>0.5286</td>
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Table 3. Inter-observer measurement agreement for CA, LCRA, and overbite

**Statistical Analysis**

Descriptive statistics were calculated. One-way ANOVA with the post-hoc Tukey-Kramer test was performed to test for a difference in CA and LCRA measurements among the four groups (Class I normal core, Class I normal expanded, Class III open bite, and Class III deep bite) or among three groups (Class I normal combined, Class III open bite, and Class III deep bite). A two-sample t-test was conducted to detect a difference in CA and LCRA between the two Class III groups. In addition, a Pearson’s
Correlation coefficient was computed to measure the strength of a linear relationship between CA and LCRA. Note that a negative coefficient indicates a decreasing relationship between the two variables, while a positive coefficient indicates increasing relationship between the two variables. The table below illustrates a guide for interpretation of strength of the relationship between the two variables. All tests utilized a 0.05 level of significance. SAS for Windows (v9.3, SAS Institute Inc, Cary, NC, USA) was used for the data analysis.

<table>
<thead>
<tr>
<th>±0.0</th>
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<tr>
<td>±0.2</td>
<td>Weak correlation</td>
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<td>±0.5</td>
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<td>±0.8</td>
<td>Strong correlation</td>
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<td>±1.0</td>
<td>Perfect correlation</td>
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</tbody>
</table>

Table 4. Interpretation of Pearson’s correlation coefficient
RESULTS

Correlation between CA and LCRA

The first aim of this study was to determine if LCRA is correlated with CA. The null hypothesis stated that there was no correlation between the two variables. Pearson’s correlation was used to detect a linear relationship between LCRA and CA.

When examining all subjects combined, a significant correlation between CA and LCRA was found with a Pearson’s correlation coefficient of 0.82 indicating there was a strong increasing relationship between the CA and LCRA (p<0.0001, Figure 5). The correlation between CA and LCRA was also examined in the groups Class I normal core, Class I normal expanded, Class I normal combined (a combination of Class I normal core and Class I normal expanded groups), Class III open bite, and Class III deep bite. For the Class I normal combined group (N=46), a Pearson’s correlation coefficient of 0.57 indicated a moderate increasing relationship between the two variables (p<0.0001, Figure 6). For the Class III open bite group (N=20) and Class III deep bite group (N=22), a Pearson correlation coefficient for both was found to be 0.85 indicating there was a strong increasing relationship between the two variables in those two groups (p<0.0001, Figures 7 and 8). No significant correlation between CA and LCRA was found for Class I normal expanded group (n=18), while there was a significant correlation between the two variables for the Class I normal core group (N=28) with a Pearson’s correlation coefficient of 0.68 indicating a moderate correlation (p<0.0001, Figure 9).
Figure 5. Correlation between CA and LCRA for all subjects*

*Pearson’s correlation coefficient of 0.82
Figure 6. Correlation between CA and LCRA for Class I normal combined group*

*Pearson’s correlation coefficient of 0.57
Figure 7. Correlation between CA and LCRA for Class III open bite group*

*Pearson’s correlation coefficient of 0.85
Figure 8. Correlation between CA and LCRA for Class III deep bite group*

*Pearson’s correlation coefficient of 0.85
Figure 9. Correlation between CA and LCRA for Class I normal core group*

*Pearson’s correlation coefficient of 0.68
Comparison of CA and LCRA among Groups

The aims of this study were to assess the differences in CA and LCRA between two, three and four groups. Descriptive statistics were calculated first, and data was then analyzed in three ways. For the first two ways, a one-way ANOVA with a post-hoc Tukey-Kramer test was used to compare subjects divided into three and four groups. The four groups included Class I normal core, Class I normal expanded, Class III open bite and Class III deep bite groups, while the three groups consisted of Class I normal combined, Class III open bite and Class III deep bite groups. The third way the data was analyzed to compare just the two groups, Class III open bite and Class III deep bite, was by using a two-sample t-test.

A total of 88 subjects (56 males and 32 females) were examined in this study. Of the 88 subjects, 28 were from Class I normal core, 18 from Class I normal expanded, 20 from Class III open bite, and 22 from Class III deep bite. Descriptive statistics are summarized in Tables 5 and 6 and shown in Figures 10 and 11.
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<thead>
<tr>
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<tr>
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<td>5.65</td>
<td>23.60</td>
<td>44.10</td>
<td>35.90</td>
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<tr>
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<td>60.60</td>
<td>34.75</td>
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Table 5. Mean CA, LCRA, and overbite by the four types of patient groups
<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
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<th>Deviation</th>
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<td>32.80</td>
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<td>32.45</td>
<td>12.78</td>
<td>7.70</td>
<td>63.40</td>
<td>31.75</td>
</tr>
</tbody>
</table>

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<th>Mean</th>
<th>Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
</tr>
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<tr>
<td>CA_JF1</td>
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<td>23.60</td>
<td>44.10</td>
<td>35.90</td>
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<tr>
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<td>-15.70</td>
<td>20.28</td>
<td>-67.10</td>
<td>-0.10</td>
<td>-7.05</td>
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Table 6. Mean CA, LCRA, and overbite by the three types of patient groups
Figure 10. Box and whisker plot of CA (y-axis) among groups (x-axis)
Figure 11. Box and whisker plot of LCRA (y-axis) among groups (x-axis)
Comparison of Four Groups for the Measurement CA

Results of a one-way ANOVA revealed that there was a significant effect for type of patient group based on CA (F(3,84)=16.8; p<0.0001). The post-hoc Tukey-Kramer test indicated that the mean CA for Class III deep bites (9.32±4.46) was significantly greater than those observed in the other three groups, while no significant differences were found among Class I normal core (3.38±1.70), Class I expanded (3.60±1.94) and Class III open bite (5.24±3.99) groups (Table 7).

<table>
<thead>
<tr>
<th>Type of Patient Group</th>
<th>N</th>
<th>Mean CA (SD)</th>
<th>Group Comparison**</th>
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<tr>
<td>Class III Deep Bite</td>
<td>22</td>
<td>9.36(4.46)</td>
<td>A</td>
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<tr>
<td>Class III Open Bite</td>
<td>20</td>
<td>5.24(3.99)</td>
<td>B</td>
</tr>
<tr>
<td>Class I Normal Expanded</td>
<td>18</td>
<td>3.60(1.94)</td>
<td>B</td>
</tr>
<tr>
<td>Class I Normal Core</td>
<td>28</td>
<td>3.38(1.70)</td>
<td>B</td>
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</table>

** Same letter are not significantly different using the post-hoc Tukey-Kramer test (P>0.05)

Table 7. Comparison of CA among four groups

Comparison of Three Groups for the Measurement CA

Combining the Class I normal core and Class I normal expanded groups into one group showed similarly in a one-way ANOVA analysis that there was again a significant effect for the patient group based on CA (F(2,85)=25.46; p<0.0001). The post-hoc Tukey-Kramer test indicated that the mean CA for Class III deep bites (9.32±4.46) was significantly greater than those observed in the other two groups, while no significant differences were found among Class I normal combined (3.47±1.78) and Class III open bite (5.24±3.99) groups (Table 8).
Table 8. Comparison of CA among three groups

<table>
<thead>
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<th>Type of Patient Group</th>
<th>N</th>
<th>Mean CA (SD)</th>
<th>Group Comparison**</th>
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<tr>
<td>Class III Deep Bite</td>
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<td>9.36(4.46)</td>
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<tr>
<td>Class III Open Bite</td>
<td>20</td>
<td>5.24(3.99)</td>
<td>B</td>
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<tr>
<td>Class I Normal Combined</td>
<td>46</td>
<td>3.47(1.78)</td>
<td>B</td>
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</table>

** Same letter are not significantly different using the post-hocTukey-Kramer test (P>0.05)

Comparison of CA between Class III Open Bite and Class III Deep Bite Groups

Based on the two-sample t-test, there was a significant difference in the mean CA between Class III open and Class III deep bite groups (p=0.0032). The data demonstrated that mean CA for Class III deep bites was significantly greater than Class III open bites (9.36±4.46 versus 5.24±3.99).

Comparison of Four Groups for the Measurement LCRA

Results of one-way ANOVA revealed that there was a significant effect for type of patient group based on LCRA (F(3,84)=10.73; p<0.0001). The post-hoc Tukey Kramer test indicated that the mean LCRA for Class III deep bites (39.67±5.64) was significantly greater than those observed in the other three groups. No significant differences were found among the Class I normal core (31.97±4.25), Class I expanded (33.53±5.65) and Class III open bite (35.55±5.65) groups (Table 9).
<table>
<thead>
<tr>
<th>Type of Patient Group</th>
<th>N</th>
<th>Mean LCRA (SD)</th>
<th>Group Comparison**</th>
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<tr>
<td>Class III Deep Bite</td>
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<td>39.67(5.64)</td>
<td>A</td>
</tr>
<tr>
<td>Class III Open Bite</td>
<td>20</td>
<td>35.55(5.65)</td>
<td>B</td>
</tr>
<tr>
<td>Class I Normal Expanded</td>
<td>18</td>
<td>33.53(4.05)</td>
<td>B</td>
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<tr>
<td>Class I Normal Core</td>
<td>28</td>
<td>31.97(4.25)</td>
<td>B</td>
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</tbody>
</table>

** Same letter are not significantly different using the post-hoc Tukey-Kramer test (P>0.05)

Table 9. Comparison of LCRA among four groups

Comparison of Three Groups for the Measurement LCRA

The results of the one-way ANOVA revealed that there was a significant effect for type of patient group based on LCRA ($F(2,85)=15.53; p<0.0001$). The post-hoc Tukey-Kramer test indicated that the mean LCRA for Class III deep bites (39.67±5.64) was significantly greater than those observed in the other two groups, while the mean LCRA for Class III open bite group (35.55±5.65) was significantly greater than that observed in the Class I normal combined group (32.58±4.20) (Table 10).

<table>
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<th>Type of Patient Group</th>
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<th>Group Comparison**</th>
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<td>A</td>
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<tr>
<td>Class III Open Bite</td>
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<td>35.55(5.65)</td>
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<tr>
<td>Class I Normal Combined</td>
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<td>32.58(4.20)</td>
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</table>

** Same letters are not significantly different using the post-hoc Tukey-Kramer test (P>0.05)

Table 10. Comparison of LCRA among three groups
Comparison of LCRA for Class III Open Bite and Class III Deep Bite Groups

Based on the two-sample t-test, there was a significant difference in mean LCRA between Class III open and Class III deep bite groups (p=0.0230). The mean LCRA for Class III deep bites was significantly greater than Class III open bites (39.67±5.64 versus 35.55±5.65). Table 10 shows a summary of descriptive statistics for LCRA.

Correlation between CA and Overbite within Two Groups

In order to evaluate if there is a linear relationship between CA and overbite, a Pearson’s correlation coefficient was calculated. There was no significant correlation between CA and overbite within the Class III open (p=0.8029) and Class III deep bite groups (p=0.2089).

Correlation between LCRA and Overbite within Two Groups

Similarly to CA, a Pearson’s coefficient was calculated to evaluate the correlation between LCRA and overbite. No significant correlation was found between LCRA and overbite within Class III open (p=0.7529) and Class III deep bite groups (p=0.1864).
DISCUSSION

Root resorption has long been recognized as a negative consequence associated with orthodontics, but only recently has it been demonstrated that some resorption occurs in almost every patient. For most teeth in most patients, the degree of root length change is so small that it is difficult to detect clinically. However, in a smaller percentage of patients, root shortening becomes obvious (Kaley and Philips, 1991). Maxillary central incisors have long been reported to be the most susceptible teeth to severe resorption most commonly reported when roots are translated through the palatal cortex (Ten Hoeve and Mulie 1976, Goldson 1975, and Kickman 1986). Kaley and Philips, who extensively reviewed the topic of root resorption, found that torqueing is the single most predisposing factor to root resorption. In general, they found root torqueing to have an odds ratio of 4.5, but this ratio increases to 20 when torqueing approximates the palatal cortex (Kaley and Phillips 1991). Although root resorption may not affect the prognosis of a tooth, it should still be a primary goal of the orthodontist to prevent it.

The concern surrounding CA is that if undetected, it will have been lost as a diagnostic tool which could alert orthodontic clinicians to the increased risk of root resorption with certain movements of the teeth.

Historically the CA of teeth has always been assumed to be zero (Germane 1989). This has been built into many prescriptions for edge-wise appliances and is built into current cephalometric tracing software. There have been several recent studies which have reported an increased CA associated with particularly Class II Division II (Delivanis 1980, Bryant 1984) and Class III malocclusions (Harris 1993), but prior to a thesis by Bauer et al no attempt was made to find the CA for Class I normal patients. Bauer, along with our current study, demonstrated that there is wide variability in the values for collum angles within specific types of malocclusions and there is an inherent difficulty in assigning these values due to difficulty with landmark identification (Bauer 2014).

To help simplify and clarify the measurement of CA, LCRA was proposed by Bauer as an alternative measurement to CA. Both Bauer and the current study found CA and LCRA to be correlated.
It is our hope that with the new LCRA measurement, clinical orthodontists may have a new tool that could help them predict cases where excessive root torque should be avoided, in order to help prevent root resorption.

**Case Report**

Use of CA and LCRA can easily be applied to both treatment and post-treatment case analysis. Patient A.H. was a 15 year 4 month old Caucasian female who presented to the University of Iowa Department Of Orthodontics for comprehensive care for Class III malocclusion. Adequate full treatment records exist.

Prior to treatment a full mouth radiographic series was taken and showed that the maxillary incisors had normal anatomy with fully formed apices and undamaged incisal edges. Visualization of the pre-treatment lateral cephalometric radiographs showed that the maxillary incisor root was in close proximity to the anterior palatal cortex prior to treatment (Figure 12).

The patient was Class III by half a step (3mm) bilaterally with anterior crossbite. Maxillary canines were completely blocked out of the arch and either un-erupted (#11) or partially erupted (#6). Also the mandibular arch had severely crowded lower anterior teeth as well. Transversely, the patient had bilateral posterior cross-bite. Measurements of the CA, LCRA, and overbite of the maxillary central incisor in the pre-treatment cephalometric radiograph were 8.4 degrees, 39 degrees and 5% respectfully (Table 9). The CA for patient A.H. was two standard deviations larger than the normal core sample mean and the LCRA angle was one standard deviation larger than the normal core sample mean.

Treatment for the patient included expansion of the maxillary arch and extraction of mandibular first premolars prior to comprehensive treatment using standard edgewise techniques with MBT prescription brackets. The post-treatment lateral cephalometric radiograph shows the maxillary central incisor roots torqued into the lingual palatal cortex. A closer view of the apices of the incisors shows significant root resorption (Figure 13).
<table>
<thead>
<tr>
<th></th>
<th>Patient A. H.</th>
<th>Mean (Standard Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class I Normal Core</td>
</tr>
<tr>
<td>CA (degrees)</td>
<td>8.4</td>
<td>3.38 (1.70)</td>
</tr>
<tr>
<td>LCRA (degrees)</td>
<td>39</td>
<td>31.97 (4.24)</td>
</tr>
</tbody>
</table>

Table 11. Comparison of mean values of CA and LCRA between A.H. (pre-treatment) and the Class I normal core group
Figure 12. Pre-treatment radiographs for Class III patient A.H.*

*Central incisor CA and LCRA in this case were 7.4 and 39 degrees. Note in the lateral cephalometric radiograph the steepness of the anterior palatal cortex which brings it in close proximity to the incisor roots. Pre-treatment radiographs of patient A.H. maxillary central incisors show normal root apices (inset).
Figure 13. Post-treatment radiographs for Class III patient A.H.*

*Note marked resorption of maxillary central incisors and close approximation of teeth to the palatal cortex in the lateral cephalometric radiograph. The post-treatment periapical film shows considerable resorption of maxillary incisor roots (inset).
The fact that there is currently only one study (Harris et al, 1984) that found an increased CA in Class III malocclusions necessitated the need for our current study (1984). This study followed the format of the thesis by Bauer and examined samples of Class I normal occlusions and two groups of Class III malocclusions, both open and deep bite subjects. The justification for comparing open and deep bite Class III subjects came from the hypothesis Harris et al proposed that lingual deflection of the upper incisor crown by the lower dental arch during tooth development in Class III Deep Bite occlusions causes “bending” of the crown-root angle. The hypothesis that the increased CA is associated with Class III malocclusions with deep overbite was supported by the results of this thesis research project. If the roots are more susceptible to environmental influences than the crowns during growth, as suggested by Harris et al, it is possible that this biologic responsiveness of the root of the upper central incisor could explain the association between CA and deep overbite.

Correlation between CA and LCRA

The first aim of this study was to look at the correlation between CA and LCRA. LCRA was previously proposed as an alternative measurement to CA in a thesis by Bauer (2014). LCRA could easily be incorporated into cephalometric tracing software since it is currently composed of points already landmarked in standard cephalometric analysis. In comparison to CA, the points are also more easily identifiable.

The high correlation found between CA and LCRA (r=0.82) for all samples combined (n=88) and Class III open (r=0.85) and deep (r=0.85) bite samples supports findings from the Bauer thesis. Therefore it is proposed that orthodontic clinicians incorporate this measurement into their cephalometric diagnosis of Class III patients.

CA and LCRA Differences between Class I Normal and Class III Open and Deep Bite Groups

The next two aims in this study were comparative analysis between Class I normal and Class III malocclusions. More specifically, the first aim looked at subjects divided into three and four groups
using a one-way ANOVA test with a post-hoc Tukey Kramer test. The four groups consisted of Class I normal core, Class I normal expanded, Class III open bite and Class III deep bite. The three groups consisted of Class I normal combined, Class III open bite and Class III deep bite. The second aim compared Class III open bites to the Class III deep bites using a two sample t-test.

Looking at the four groups, the CA and LCRA were significantly higher for the Class III deep bite group compared to the other three groups. Mean CA (SD) for the Class I normal group, class I expanded group, Class III open bite group and Class III deep bite group were 3.38(1.70), 3.60(1.94), 5.24(3.99) and 9.36(4.46). Mean LCRA (SD) for the Class I normal group, class I expanded group, Class III open bite group and Class III deep bite group were 31.97(4.25), 33.53(4.05), 35.55(5.65) and 39.67(5.65).

Looking at the three groups, the CA and LCRA were significantly higher again for the Class III deep bite group compared to the other two groups. Mean CA (SD) for the Class I combined group, Class III open bite group and Class III deep bite group were 3.47(1.78), 5.24(3.99) and 9.36(4.46). Mean LCRA (SD) for the Class I combined group, Class III open bite group and Class III deep bite group were 32.58(4.20), 35.55(5.65) and 39.67(5.64).

Lastly, comparing the Class III open bites and Class III deep bites using a two sample t-test, it was again demonstrated that Class III deep bites had significantly higher values for CA (9.36 versus 5.24, p=0.0032) and LCRA (39.67 versus 35.55, p=0.0230).

Therefore the null hypothesis was rejected and it was concluded that the mean CA and LCRA values observed in Class III deep bites were statistically different from those observed in Class I normal bites and Class III open bites. These findings support the hypothesis proposed by Harris which states lingual deflection of the upper incisor crown by the lower dental arch during tooth development causes “bending” of the crown-root angle (1984).
Correlation between CA and LCRA and Overbite

The last specific aim in this study was to evaluate whether there was a linear relationship between CA and LCRA and overbite in Class III open bite and Class III deep bite groups. In all cases, there was found to be no correlation. Therefore, it can be concluded that the amount of overbite doesn’t necessarily correspond to higher or lower values for CA or LCRA but only that the fact that the patient is either open or deep is correlated with higher CA or LCRA in general.

Limitations of the Study

Records and sample size. The samples obtained from the Iowa Growth Study originated in the 1940s so although the records are in good shape, some radiographs could not be used due to blemishes or scratches. Likewise, Class III malocclusions were more difficult to find due to decreased incidence in the population in general compounded with the strict criteria set by this study for having high enough quality radiographs that the required landmarks could be readily identified. Limitations of a relatively small sample size typically reduce statistical power substantially.

Measurement error and study design. No cephalometric study can be complete without mentioning the possibility of measurement error and the limitations of cephalometric analysis in general. Dolphin imaging software (version 11.5) reports angular measurements to the nearest tenth of a degree but depending on slight movements of points, the angles can be skewed one way or another fairly quickly.

This study arbitrarily set 1.5 degrees as the tolerance above which measurements had to be re-measured, continuing the design used in the Bauer thesis (2014). It is unknown whether any attempt has previously been made to establish reliability limits for CA. The closest example found was in a study by Baumrind and Frantz (1971), where five judges completed measurements on 20 cephalometric radiographs and found a standard deviation of the interincisal angle measurement to be 3.54 (1971). Nowhere in the study was there a theory as to where the error came from. In the current study, the
possibility of observer agreement must be taken into account as the difference between the Class I normal and Class III deep bites means for CA and LCRA were 5.79 and 7.09 respectively.

It must also be mentioned that this study discarded radiographs which lacked clarity. While this may have idealized the study it also limited the study in terms of sample size. Measurements made in clinical practice would not have the liberty to pick and choose radiographs for measurement which is a limitation as to the applicability of this study.

**General reliability and external validity.** For the samples, 97% consisted of patients from northwestern European decent. Therefore, application to the population at large may be limited due the homogeneity of the current study. Further studies would be needed to establish norms for other ethnic groups.

**Future Research**

This study attempted to establish mean values for the crown-root relationships of subjects with Class I normal occlusion and Class III malocclusions. Since the Iowa Growth Study consisted of 97% of patients from northwestern European decent, it would be advantageous to look at norms from other ethnic groups. Bauer’s thesis (2014), which utilized Iowa Growth Study patients, also examined Class II Division II patients that have been shown previously to have increased CA in the literature (2013). It would be interesting to look for other factors, such as overbite for example, which could contribute the increased CA and LCRA in Class II Division II and other malocclusions.
CONCLUSIONS

Based on the findings of this investigation, the following conclusions can be drawn:

1. LCRA and CA were highly correlated in Class III patients.

2. Patients with Class III deep bites had statistically higher means for CA and LCRA than patients with Class I normal occlusions and Class III open bite malocclusions.

3. There was no significant correlation between the measures for overbite and either CA or LCRA values in Class III patients.
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