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Crown size comparisons in patients with unilateral palatally displaced canines

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Crown size comparisons in patients with unilateral palatally displaced canines

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

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Abstract

CROWN SIZE COMPARISONS IN PATIENTS WITH PALATALLY DISPLACED CANINES

By Joseph L. Eliason, D.D.S.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2015
Thesis Director: Steven J. Lindauer, D.M.D., M.Dent.Sc.
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There has been significant debate over the past decades regarding the etiology of palatally displaced canines. Theorized risk factors include agenesis or malformation of the lateral incisors, incisor retroclination, transverse deficiency, or genetic predisposition. The purpose of this study is to compare the linear and volumetric measurements of canines and lateral incisors to determine how tooth size relates to canine impaction. Cone-beam CT images for 40 patients with unilateral palatally displaced canines were utilized to measure the linear dimensions and total crown volume of canines and lateral incisors and to compare those teeth on the impaction side with their isomers on the non-impaction side. Results showed that unilateral palatally impacted maxillary canine crowns were slightly, but statistically significantly wider and larger in volume than their non-impacted isomers. Lateral incisor crowns adjacent to impacted canines were significantly shorter than those adjacent to non-impacted canines.

Introduction

Impaction of permanent maxillary canines occurs in approximately 2% of the

population, although it is many times more common among patients seeking orthodontic care.[1]

These impacted teeth can be difficult to manage orthodontically. Even when the possibility of

impaction is detected at an early age, there may be some uncertainty as to whether the

impaction is inevitable, when to render treatment, and how best to intervene. While impacted

canines can occur at any depth within the alveolus, 75-85% are found on the palatal side.[2-4]

Among these palatally displaced canines (PDC), unilateral impaction is most common, occurring

in 66% of affected patients with a slight predilection for the right side.[5] The remaining 34% of

impactions occur bilaterally.[5,6] Gender also plays a role, with females up to 2.6 times more likely

than males to experience PDC.[7,8] In approaching the diagnosis and treatment planning of

impacted canines it is important for the clinician to understand the etiology behind impaction

as well as the general dental and occlusal conditions commonly found in patients with PDC.

There can be a considerable amount of uncertainty, especially in the late mixed

dentition, as to whether some canines will continue on toward eruption or impaction. The

eventual destiny of a canine is important for developing an orthodontic treatment plan, and

clues to this destiny would aid a practitioner in weighing different treatment options. Several

studies have been conducted to analyze several potential indicators for future canine

impaction. Among the most cited, Lindauer et al.[9] assessed the radiographic position of

impacted canines during the late mixed dentition and found that the location of the crown relative to the lateral incisor root was able to predict impaction or non-impaction with 78% sensitivity and 96% specificity.[9,10] Sambataro et al.[11] utilized PA cephalograms to compare the transverse position of the canine relative to the overall transverse width of the maxilla and generated a mathematical model for predicting canine impaction with a 5% probability of error. Further predictive variables would contribute to the clinician's ability to anticipate the necessity and timing of treatment for individuals with suspected impactions.

There are two predominant theories regarding the underlying mechanism causing PDC: the genetic theory and the guidance theory. The genetic theory proposes that PDC occurs as a result of polygenic, multifactorial inheritance.[8] This conclusion is drawn from several studies relating canine impaction to other dental anomalies, as well as demonstrating the influence of pedigree, population, and gender on the prevalence of impaction. It has been well documented that hypodontia increases the risk of PDC by as much as five-fold, especially when third molars, second premolars, or lateral incisors are missing,[6,12-14] and that teeth in patients with PDC are smaller in general when compared to those of controls.[15] Peck et al.[16] speculated that the association between PDC and tooth agenesis pointed to the PAX9 and MSX1 genes as possible contributors for both conditions. Pirinen et al.[17] likewise asserted a genetic origin for PDC by noting that 36% of affected patients were congenitally missing other teeth, as were 20% of both their first and second degree relatives. 5% of the overall pedigree for affected patients also demonstrated PDC. These percentages represent elevations several times above the normal population prevalence.

The guidance theory, on the other hand, suggests that normal canine eruption is partially dependent upon guidance from the root of the lateral incisor, and that canine ectopia results when the developing canine fails to locate and follow its adjacent incisor. Agenesis or abnormal morphology of the lateral incisor has been implicated as the cause for a lack of guidance for the canine, as has excessive labial root position of the lateral incisors as is often seen in patients with Angle Class II, division 2 malocclusions.[4,18] Ludicke et al.[4] and Al-Nimri and Gharaibeh[19] showed that, compared to the 10-15% prevalence of Class II division 2 malocclusion in the general population, roughly 45% of PDC patients demonstrated this occlusal scheme in their studies. Becker et al.[20] showed that only 52% of PDC patients had lateral incisors of normal dimensions, with the remaining 48% being small, peg-shaped, or missing entirely. They speculated that since abnormally small teeth tend to develop later, they may not produce a large enough footprint for the canine to follow during a critical period in its development.[20]

The length of the canine's eruption pathway itself may introduce more opportunities for deviation and subsequent impaction. This pathway has been studied and described in the scientific literature for over half a century by several prominent investigators. Coulter and Richardson[21] summarized: "all authors agree that the maxillary canine follows a longer, more tortuous path of eruption than any other tooth," indicating the inherent predisposition this creates for impaction. From the time the crown of the tooth is developed until it reaches the occlusal plane, it will travel approximately 11.5 mm posteriorly, 18.5 mm inferiorly, 2.5 mm palatally, and then ultimately 5 mm labially. The total pathway covers 22mm on average in several planes of space.[21] Further complicating the eruption process, patients with PDC have

been shown to exhibit delays in dental development ranging from 7 to 18 months compared to control subjects, and those with unilateral PDC were more delayed on the impacted side than on the non-impacted side.[7,22] Becker et al.[20] theorized that these delayed, smaller lateral incisors acted as barriers to the eruption of the canines, unable to provide adequate guidance but capable of blocking their final migration labially and inferiorly.

There has been some disagreement as to whether maxillary transverse dimensional differences are related to canine impaction. Kim et al.[23] found that PDC patients were an average of 2mm more narrow, with a palatal vault 2.3 mm higher, than matched controls. Schindel and Duffy[24] compared the radiographic position of canine cusps in patients with posterior crossbite in the mixed dentition and found that 54% of patients had canine cusps that were mesial to the distal border of the root of the lateral incisor. Lindauer et al.[9] showed that canines in this position are very likely to become impacted. Only 19% of patients without crossbite were found to have canines so far mesial.[24] In contrast, Saiar et al.,[25] Langberg and Peck,[26] Yan et al.,[27] and Anic-Milosevic et al.,[28] did not find significant differences in maxillary width between PDC and control groups, and Yan et al. found that only buccally impacted canines were associated with transverse deficiency. Al-Nimri and Gharaibeh[19] actually found transverse excess in the PDC group and speculated that excess palatal width may be a factor in the etiology of impaction.

Still other contributing mechanisms have been assessed, including trauma, dental crowding, or the length of the eruption pathway itself. While trauma has been confirmed as a contributor to canine impaction in very specific cases,[29] dental crowding has almost invariably been discounted as a factor. Jacoby[30] attributed space deficiency primarily to buccal impactions

and showed that 85% of palatally impacted canines had enough space to erupt. His assertion was supported by other studies which have shown no association between arch length insufficiency and palatal impactions.[19,31] While there are several theories behind the cause of PDC, most authors agree that the etiology is likely multifactorial.

Cone-beam computed tomography (CBCT) has been increasingly utilized in clinical orthodontics to determine the exact location and orientation of impacted canines. A cone-beam CT generates an image by exposing a target region to a rotating cone of x-radiation. This radiation is detected by a sensor that converts the data to form voxels, the three-dimensional equivalent of the standard two-dimensional pixel. These individual voxels, combined, form a composite three-dimensional image that can be viewed as a whole or in two-dimensional slices as thin as a single voxel.

The density of various hard and soft tissues within a CBCT scan is reported in Hounsfield units (HU), which is a relative comparison to the radiodensity of distilled water at Standard Temperature and Pressure (STP). At STP, distilled water measures 0 HU and air measures -1000 HU. Numerous studies have estimated the mean radiodensity of dentoalveolar hard and soft tissues. Cancellous maxillary bone in the region of the canines has been recorded in the range of 279-395 HU, with the more dense cortical bone in the same region at 741-1113 HU.[32,33] Dentin measures approximately 1700-2100 HU, and enamel is 2200-4500 HU.[34]

The clinical utilization of 3-dimensional CBCT scans for diagnosing canine impactions and for treatment planning ensures that proper consideration can be given to the surgical exposure site, the vector of orthodontic force, and the health of the impacted and adjacent teeth. In addition to their clinical benefits, several investigators have also studied these images in order

to find associations between canine ectopia and the skeletal and dental characteristics of patients with impactions. To date, however, no study has evaluated the linear dimensions and overall crown volume of the impacted canine itself as a possible factor in predicting its eventual impaction. CBCT imaging software is able to provide these measurements accurately by allowing an investigator to position the tooth in a standardized orientation and make measurements in a uniform fashion conducive to comparison.

The purpose of the present study was to determine whether the mesiodistal, labiolingual, and occlusogingival dimensions, as well as the total crown volumes of unilateral palatally impacted maxillary canines and their adjacent lateral incisors, differed from those of contralateral canines and incisors that erupted uneventfully. CBCT images were utilized to measure linear dimensions and total crown volume of each tooth in question. The null hypothesis was that there would be no significant differences in size between canines and lateral incisors on the impaction side when compared to the same teeth on the non-impaction side.

Materials and Methods

Approval to conduct this study was granted by the Institutional Review Board at Virginia Commonwealth University. Pre-treatment cone-beam CT images of patients with unilateral palatally displaced maxillary canines were collected from patient records at the Virginia Commonwealth University Department of Orthodontics, and from a private orthodontic practice in Midlothian, VA. A power analysis was completed based upon a previous study aimed at detecting differences in canine and lateral incisor dimensions between males and females.[35] That study was able to find differences of 0.4 mm (±0.5 mm) or greater between groups. In order to detect differences of the same magnitude with an alpha value of 0.05 and 80% power, a sample size of n=40 was required.

The diagnosis of canine impaction was made through retrospective evaluation of patient records, and canines labeled as impacted were required to demonstrate at least 2/3 completion of root formation without eruption into the oral cavity. In addition, the cusp tip of the impacted canine was required to lie palatal to the root of the lateral incisor in the transverse plane of the CBCT scan. The exclusion criteria for this study were: 1) one or both lateral incisors were missing, 2) the impaction was accompanied by an obvious craniofacial anomaly or syndromic condition, 3) there was any clear sign of attrition or damage to the crowns of the canines or lateral incisors, and 4) the canines or lateral incisors had any dental restorations. Demographic

data for the sample was made anonymous and included the patient's gender, ethnicity, and the side on which the impaction occurred (Table 1).

All scans were large field-of-view scans taken with either the NewTom VGi Flex (Newtom, Verona, Italy) or the 17-19 iCAT (Imaging Sciences International, Hatfield, PA) imaging systems. The scanning parameters for images varied from 110-120 kVp and 2-5 mA, with a scan time of 4-7 seconds. The voxel size was 0.2-0.4 mm. Because of the variability in kilovoltage, milliamperage, and voxel size between different scanners, unilateral impactions were evaluated in order to utilize contralateral, non-impacted canines as matched controls. DICOM files were imported into a CBCT imaging software (Invivo5, Anatomage, San Jose, CA) which allowed for the separation and visualization of hard tissues based upon grayscale density, as measured in Hounsfield Units (HU)

Canines and lateral incisors were evaluated on both the impacted and non-impacted sides using an adaptation of previously published methods for CBCT segmentation and volume rendering:[36-38] Axial images were used to determine grayscale threshold values in HU that could be used to separate the various tissues of the teeth and periodontium. These values were initially estimated using previously published findings,[32-34] but were then individualized for each subject's scan. Once an optimal range of radiodensity was determined for each patient, all volume measurements within that patient were completed using the same threshold values. The anatomical crowns of the maxillary canines and lateral incisors were separated from adjacent hard tissues within the CBCT image by setting grayscale threshold values that would highlight only the enamel outline of the crowns. This outline was then used to isolate the crowns from roots (Figure 1a). Once the crown was completely isolated, grayscale values were

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Patient	Side	Ethnicity	Gender
1	R	A	F
2	L	AA	F
3	R	C	M
4	R	C	F
5	L	C	M
6	R	C	F
7	L	AA	F
8	R	AA	F
9	L	AA	F
10	L	AA	M
11	L	C	F
12	L	C	F
13	L	C	F
14	L	AA	F
15	L	AA	M
16	R	H	F
17	R	AA	M
18	R	AA	M
19	L	H	F
20	R	C	F
21	R	AA	F
22	L	H	F
23	L	AA	F
24	L	C	F
25	L	C	F
26	L	C	F
27	R	C	F
28	R	C	F
29	R	C	M
30	R	C	M
31	L	C	F
32	L	C	F
33	R	C	F
34	R	C	F
35	R	AA	M
36	R	AA	F
37	L	AA	F
38	R	C	F
39	R	AA	F
40	R	C	F

Table 1. Individual subject demographic data.
Side: R=Right, L=Left
Ethnicity: C=Caucasian, AA=African American, H=Hispanic, A=Asian
Gender: M=Male, F=Female

adjusted to include the entirety of the crown, including the enamel and all dentin and pulpal tissues coronal to the cemento-enamel junction. Volume rendering was then completed on the isolated image (Figure 1b).

In addition to total crown volume, individual linear measurements were obtained using axial slices of the CBCT scan to assess the mesiodistal (MD) width, incisogingival (IG) height, and labiolingual (LL) thickness of each crown. This was done by orienting each tooth along its long axis and measuring the greatest distance in each respective plane: parallel to the long axis for incisogingival height, and perpendicular to the long axis for the mesiodistal width and labiolingual thickness (Figure 2). Intra-rater reliability was determined by repeating all linear and volumetric measurements for 10 randomly selected subjects after a 10-week washout period and calculating the intraclass correlation coefficients.

Each of the measurements for the canines and lateral incisors on the impacted side were compared to the same measurements on the non-impacted side. Canine measurements were also combined with measurements from the ipsilateral incisor to create a lateral incisor/canine ratio for each dimension. This ratio was compared between impacted and non-impacted sides to further elucidate whether canine crown size alone affects the rate of impaction, or if there may also have been a combined effect from the size of the lateral incisors. With consideration to the guidance theory of canine eruption, this ratio was intended to provide evidence to determine whether there was a minimum size proportion between a lateral incisor and a canine beyond which normal guidance and eruption could be expected. Significant differences between impacted and non-impacted canines and their respective lateral
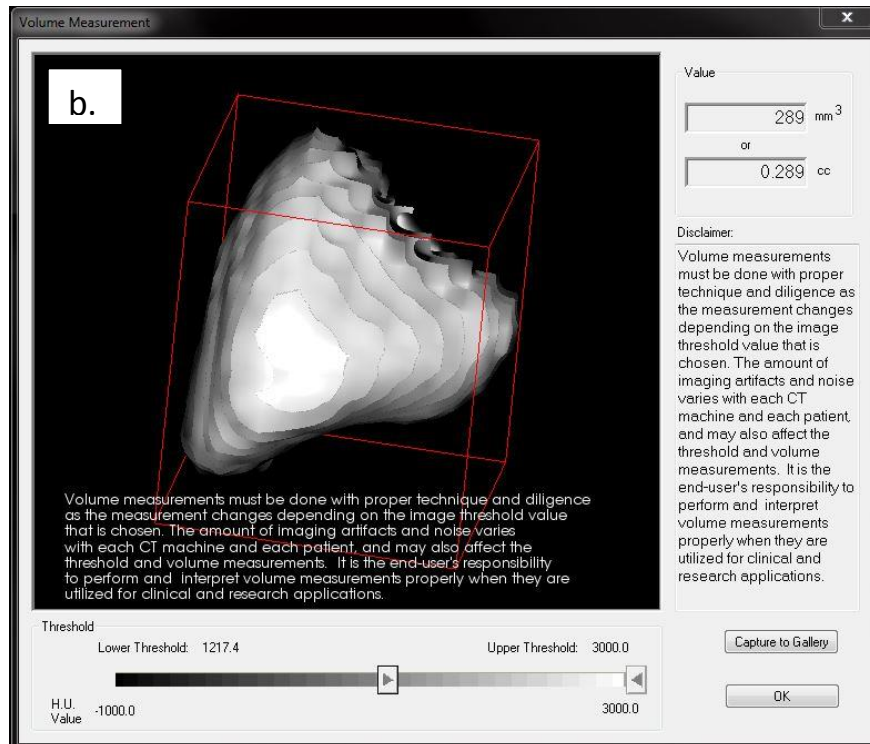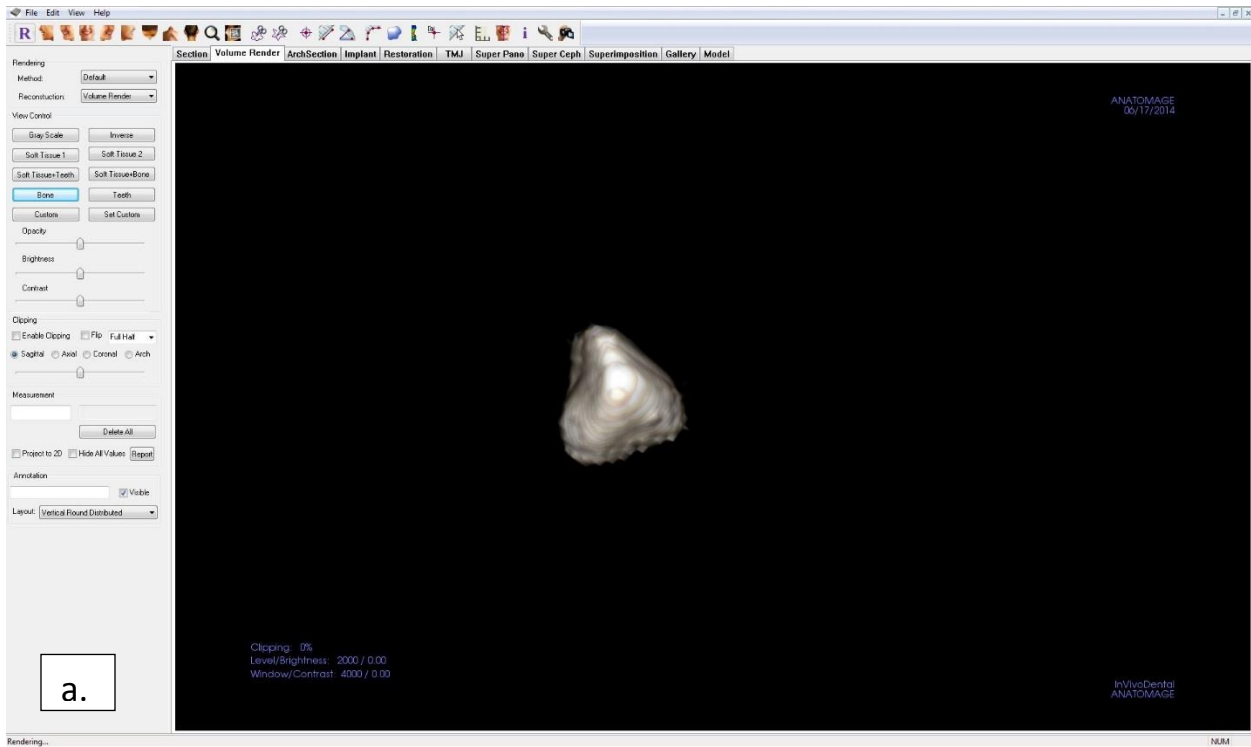
Figure 1. CBCT volume rendering: a) Isolation of the anatomic crown, and b) Volumetric measurement.
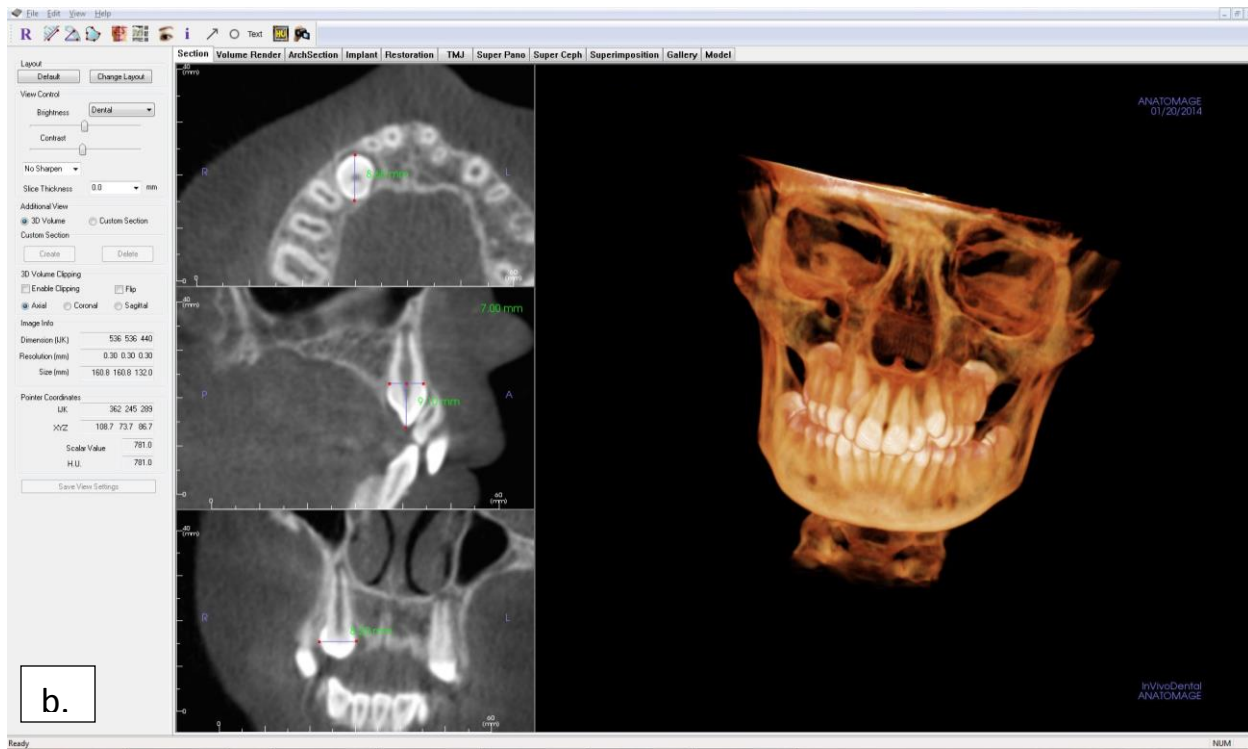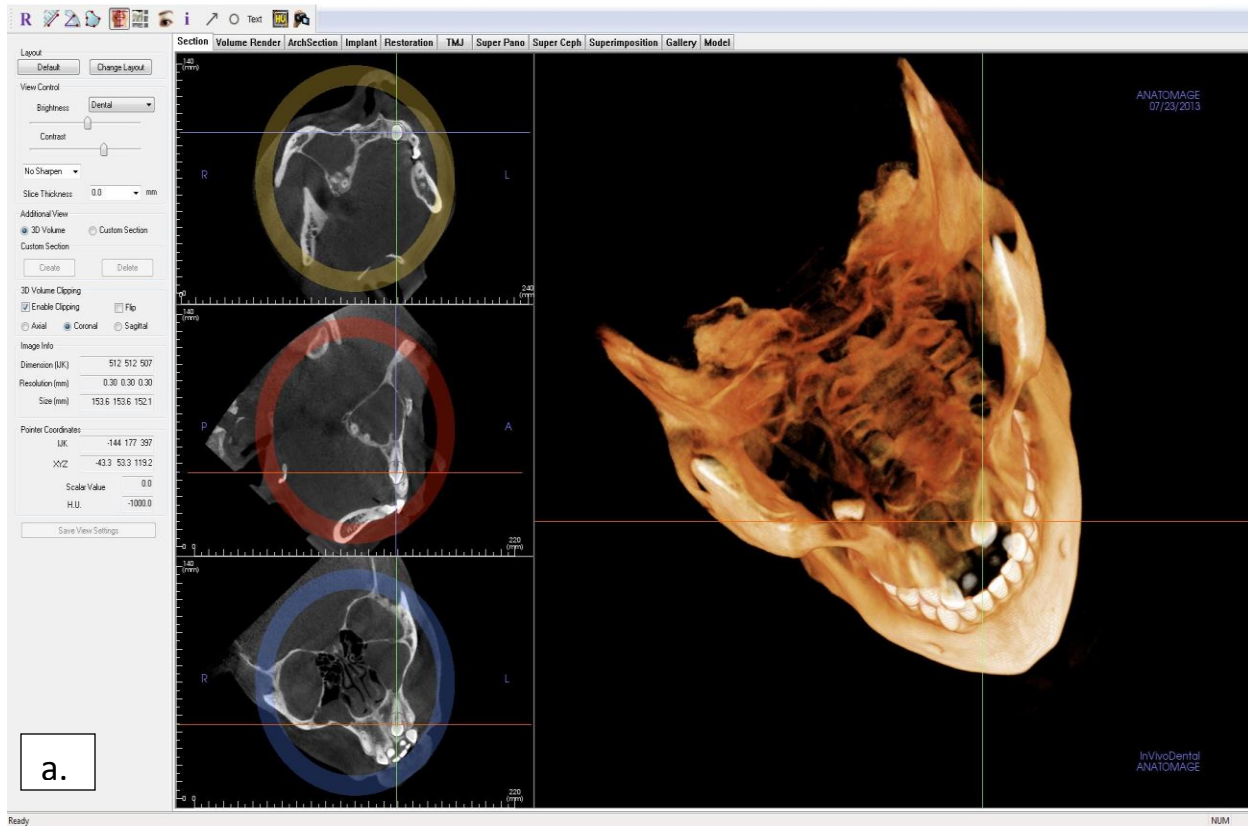
Figure 2. Sample CBCT images: a) Orientation of axial slices, and b) Linear measurements.

incisors were evaluated to test the null hypothesis that canine and lateral incisor dimensions between the two groups were not different.

Four measurements in each of the maxillary canines and lateral incisors resulted in a total of eight comparisons per individual subject. The comparison of interest was between the canine and the lateral incisor on the impacted side versus the same teeth on the control side. These 8 comparisons were tested using the Bonferroni-corrected alpha-level (0.05/8 = .00625). Differences between the two groups were evaluated using paired t-tests. Results were tested for significance at p<.00625.

Results

The intra-rater reliability in this study, shown in Table 2, was excellent, with an intraclass correlation of $r>0.92$ for all quantitative variables. Demographic information showed a 3:1 ratio of females to males, a slight predilection for impaction on the left side, and an ethnic distribution characteristic of the region in which the study took place (U.S. 2010 Census data) (Table 3 and Figure 3).

The average dimensions and volumes of teeth on the impacted and non-impacted sides are shown in Table 4 and Figure 4. The data showed that, in some dimensions, impacted canines were larger than their non-impacted isomers. The mesiodistal dimension of impacted canines was 0.28mm wider and the total crown volume was also 16mm^3 greater than the contralateral canines. These differences, although small, were relatively consistent throughout the sample and were highly significant ($p<.001$). The incisogingival height also tended to be longer among PDCs, although the level of significance ($p=.012$) did not satisfy the Bonferroni-adjusted alpha level of .00625. There were no differences found in the labiolingual thickness of the PDCs relative to control.

The lateral incisors were not significantly different in mesiodistal width or labiolingual thickness when comparing the impaction and non-impaction sides. The incisogingival height, however, was shorter by 0.45 mm in lateral incisors that were adjacent to a PDC ($p<.001$).

Impaction Side								
Canine: M-D	Canine: F-L	Canine: I-G	Canine: Vol		Lateral: M-D	Lateral: F-L	Lateral: I-G	Lateral: Vol
0.93	0.96	0.98	0.97		0.98	0.97	0.96	0.99
Non-Impaction Side								
Canine: M-D	Canine: F-L	Canine: I-G	Canine: Vol		Lateral: M-D	Lateral: F-L	Lateral: I-G	Lateral: Vol
0.90	0.96	0.98	0.92		0.97	0.93	0.97	0.96

Table 2. Intraclass correlation values.   r≥0.92 for all repeated measurements.

Demographic Information	
Side of Impaction	
Right	21
Left	19
Ethnicity	
Caucasian	21
Black	15
Hispanic	3
Asian	1
Gender	
Female	31
Male	9

Table 3. Demographic distribution of the sample.
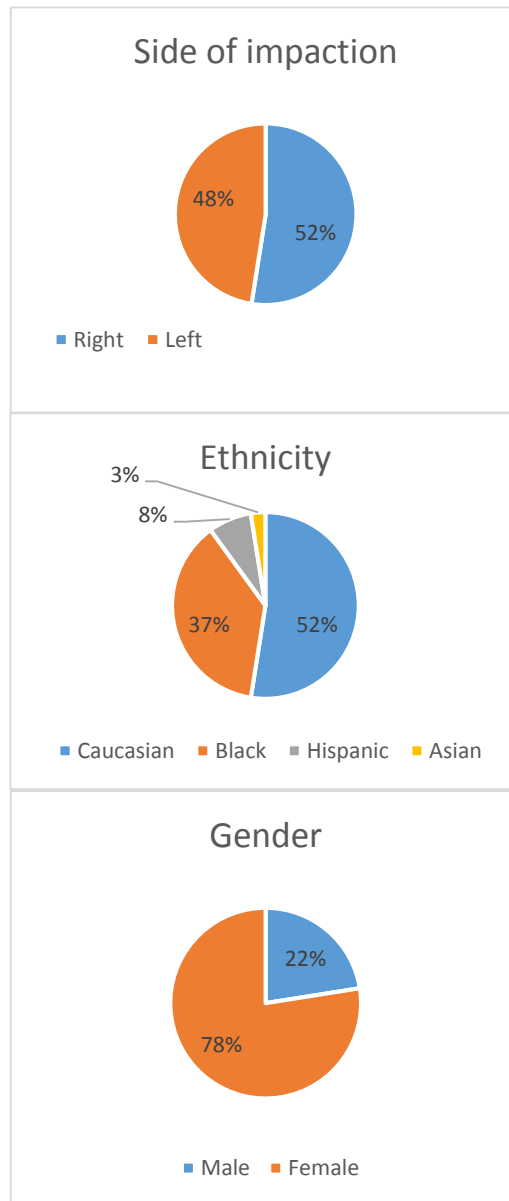
Figure 3. Distribution of sample demographic information.

	Canines						Lateral Incisors					
	Impacted	S.D.	Non-Impacted	S.D.	Difference	p-value	Impacted side	S.D.	Non-impacted side	S.D.	Difference	p-value
Mesiodistal (mm)	8.21	0.53	7.93	0.56	0.28	p<0.001*	6.94	0.70	6.99	0.64	-0.05	0.394
Labiolingual (mm)	8.80	0.55	8.72	0.74	0.08	0.340	6.76	0.44	6.85	0.56	-0.09	0.234
Incisogingival (mm)	10.26	1.04	9.99	0.99	0.27	0.012†	9.02	1.08	9.47	0.86	-0.45	p<0.001*
Volume (mm³)	333.95	6.87	318.13	6.96	15.82	p<0.001*	212.35	5.35	221.83	5.24	-9.48	0.019†

Table 4. Differences in linear (mm) and volumetric (mm^3) measurements between impaction and non-impaction sides.

* p<.00625 Significant after Bonferroni correction

† p<.05 Not significant after Bonferroni correction.
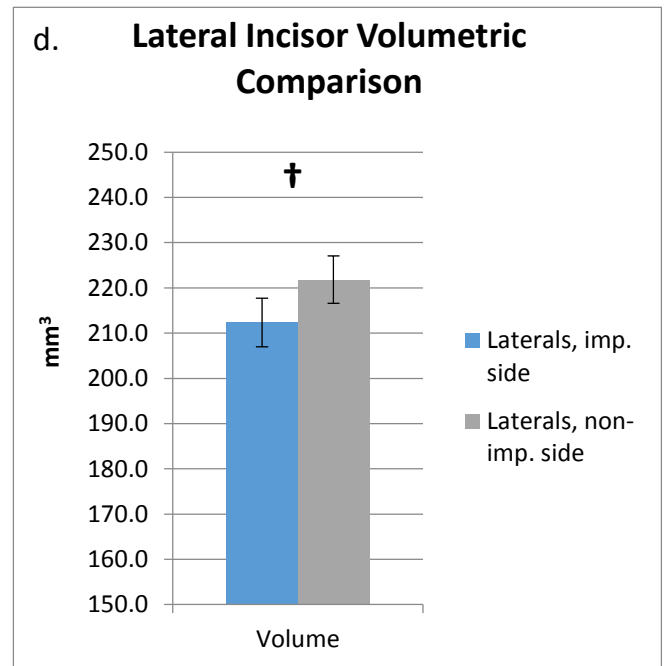
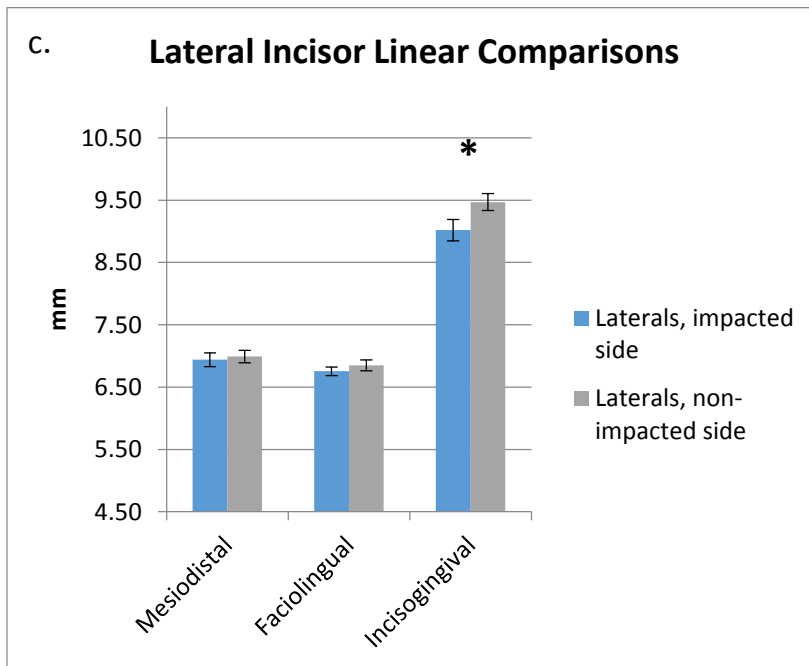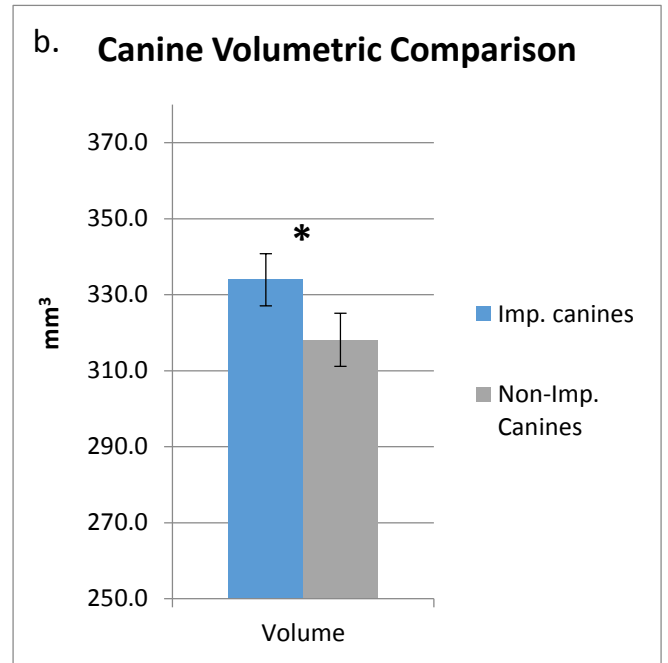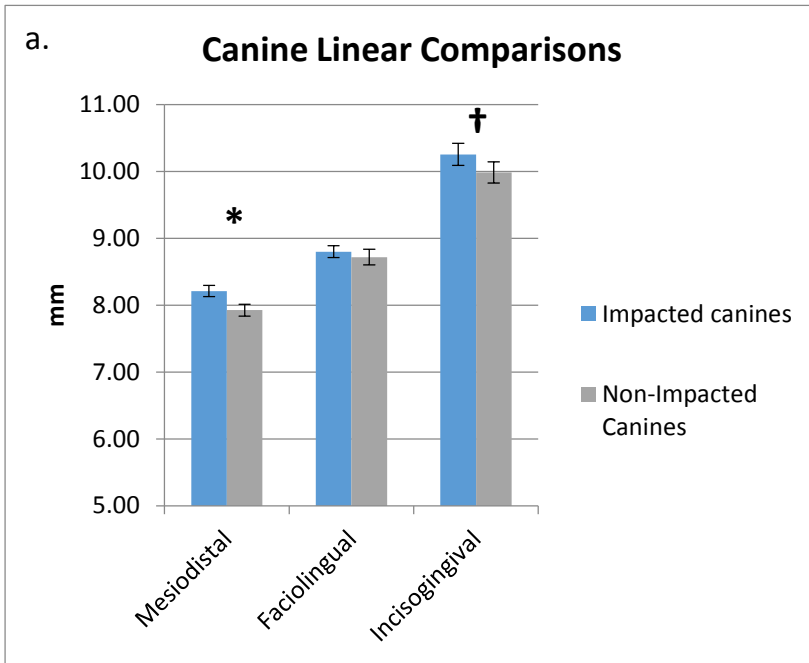S.D=Standard deviation

Figure 4. Comparisons between linear and volumetric measurements on impaction side and non-impaction sides: a) Canine linear measurements, b) Canine volumetric measurements, c) Lateral incisor linear measurements, and d) Lateral incisor volumetric measurements.

* p<.00625 Significant after Bonferroni correction
† p<.05 Not significant after Bonferroni correction.

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Consequently, the volume of the lateral crowns on the PDC side tended to be slightly smaller, although the difference was marginal at 10 mm^3 (p=.019).

Ratios of lateral incisor to canine measurements were compared to determine if there were any significant differences in the proportional size of the canine relative and its adjacent incisor. The lateral incisor/canine ratios confirmed the differences detected in the individual measurements. In the impaction group, the proportional size of the lateral incisor to the canine was smaller in every dimension, with a statistically significant difference in the mesiodistal (p=.002), incisogingival (p<.001), and total volume (p<.001) measurements. The lateral incisor/canine ratio for the labiolingual dimension was not significantly different (Table 5).

Lateral Incisor/Canine Ratio			
	Impaction	Non-Impaction	p-value
Mesiodistal	0.846	0.885	0.002*
Labiolingual	0.769	0.792	0.228
Incisogingival	0.882	0.952	p<0.001*
Volume	0.640	0.701	p<0.001*

Table 5. Size proportion of the lateral incisor to the adjacent canine.
* p<.00625 Significant after Bonferroni correction.

Odds Ratio (For 0.1 mm increase)		95% CI	P-value
Canine: Mesiodistal	2.78	1.261-6.112	0.0112
Lateral: Incisogingival	0.54	0.313-0.930	0.0263

Odds Ratio (For 0.25 mm increase)		95% CI	P-value
Canine: Mesiodistal	12.85	1.787-92.345	0.0112
Lateral: Incisogingival	0.21	0.055-0.834	0.0263

Table 6. Conditional logistic regression model showing statistically significant odds ratios for increases in linear dimensions.

Discussion

The findings of the present study indicated that impacted canines, measured radiographically while still unerupted, tended to be larger than their non-impacted isomers. Not surprisingly, the wider mesiodistal dimension of the impacted canines was associated with a larger total crown volume as well. The lateral incisor crowns adjacent to impacted canines were shorter by nearly 0.5 mm when compared to the same tooth on the non-impacted side. The results of the comparisons in this study provide valuable insight into the relationship between the sizes of canines and lateral incisors and palatal canine impaction.

The results corroborate those found in a similar study by Yan et al. in 2013.[27] The authors of that study evaluated linear measurements of impacted canines by comparing across two distinct groups: one in which patients presented with unilateral or bilateral PDC, and one in which both canines erupted normally. Between the two groups, no significant differences were detected. However, when the authors evaluated only those patients with unilateral PDC and compared the measurements of the contralateral canines within individuals, they found a statistically significant increase of 0.27 mm mesiodistally in PDCs, almost identical to the findings of this study.

The significant linear differences detected in the present study (mesiodistal of the canine and incisogingival of the lateral incisor) were used to calculate odds ratios for the development of canine impaction using a conditional logistic regression model. Table 6

demonstrates how the odds are affected by an increase of 0.1 mm or 0.25 mm in these dimensions. The ranges of the 95% confidence intervals are quite high, indicating a lack of precision in the odds ratio but confirming that the risk is indeed elevated as the size of one tooth increases relative to its isomer.

Variability in the size and shape of isomeric teeth within the same dental arch has been well documented in previous studies. Likewise, it has been postulated that smaller lateral incisors are less likely to provide adequate guidance for the eruption of developing canines, conforming to the Guidance Theory of canine eruption described by Becker et al.[20] If there exists an ideal ratio in the size of the lateral incisor relative to its adjacent canine, perhaps a larger canine with an average-sized lateral incisor would produce a size discrepancy similar to an average-sized canine with a small lateral incisor. In both cases, the lateral incisor may not be of adequate size relative to the canine to provide the guidance needed for successful eruption. To assess the possibility that this disproportional relationship is associated with the rate of impaction, the lateral incisor to adjacent canine ratio for each dimension was compared between impacted and non-impacted sides. Comparing the impacted and non-impacted sides in this manner (Table 5), the only significant differences in the lateral incisor/canine ratios were in the same categories found to be different in the individual measurements, namely the mesiodistal width and crown volume of the canines and the incisogingival height of the lateral incisors. No additional significant differences were observed, suggesting that the comparative size of the lateral incisor to its adjacent canine did not influence the likelihood of impaction any more than the individual measurements of the teeth.

Another possibility for the observed difference in size may be due to the erupted canine experiencing more attrition, erosion, and abrasion while functioning in the oral cavity than its impacted isomer. The lateral incisor near the impacted canine, which tended to be smaller incisogingivally, may also have experienced more wear. In the absence of canine guidance during lateral excursions, there may have been more opportunity for wear against the incisal edge of the lateral incisor on the impaction side, leading to decreased height among those teeth. Even so, the difference in height among the groups of lateral incisors was 0.45mm, and it is unlikely that such a noticeable difference would be attributed to attrition, due to the fact that teeth with obvious signs of wear were excluded from this study.

This study did not find a difference in the mesiodistal width of lateral incisors on the impaction and non-impaction side. Previously published findings have suggested, however, that lateral incisors adjacent to impacted canines tended to be slightly smaller than those on the non-impacted side. In some of those studies, that trend approached statistical significance, while in others it remained only a suggestive trend. Becker et al.,[20] Al-Nimri and Gharaibeh,[19] and Anic-Milosevic et al.[28] noted that lateral incisors adjacent to PDC were smaller mesiodistally at a magnitude of only 0.2-0.3 mm, with no statistical difference. On the other hand, Langberg and Peck,[26] Liuk et al.,[38] and Yan et al.[27] all found differences of very similar value and were able to demonstrate significance. However, their studies compared separate impaction groups and control groups instead of unilateral impactions with contralateral controls. In fact, when Yan et al.[27] narrowed their comparisons to unilateral PDC with contralateral control teeth, they noted that there was no longer a statistical difference in lateral incisor tooth size. Some inferences can be made when comparing these previous studies with the current study: 1) the differences in

tooth size between subjects with and without PDC are very small, whether or not they were

shown to be statistically significant, and 2) the teeth in general may be smaller among subjects

with PDC, minimizing the difference in tooth size observed during intraarch comparisons but

accentuating the difference when comparing separate PDC and control groups.

The idea that teeth may be smaller in patients with PDC is substantiated in the scientific

literature. Chaushu et al.[31] demonstrated that teeth in patients with PDC were consistently

smaller than patients with buccal impactions and Langberg and Peck[26] showed that maxillary

and mandibular incisors were narrower by nearly 0.5 mm on average compared to patients

without impaction. They concluded that there was a generalized tooth-size reduction affecting

more than just the lateral incisors in patients with PDC, and used these data as further evidence

in support of the genetic theory of canine impaction.

In addition to comparing the paired values of each measurement, the lateral incisors in

this study were also evaluated individually to determine how often they deviated from their

expected dimensions in either the impaction or non-impaction group. Utilizing published data

on normative tooth size proportions,[39] lateral incisors were categorized as "narrow" in the

mesiodistal dimension and "short" in the incisogingival dimension if their proportions to the

adjacent canine were below one standard deviation of the expected value. Using one standard

deviation as the cutoff point resulted in the labelling of teeth that would be statistically

expected to represent the smallest 17.5% of lateral incisors adjacent to a canine of a given size.

The number of lateral incisors that were shorter or more narrow than expected was then

quantified on the PDC side as well as the control side. 11 of the 40 (28%) lateral incisors in the

impaction side were categorized as narrow, compared to only 5 on the non-impaction side

(13%). In the incisogingival dimension there were 2 lateral incisors that were categorized as "short" on the impaction side, with no short lateral incisors found on the non-impaction side. The sample size was too small to test the statistical significance of these differences, but an increased number of smaller lateral incisors adjacent to impacted canines is a trend that has been noted in other studies.[12,20,38] The statistically significant findings observed in other papers have been cited as evidence for a localized, rather than generalized, reduction in tooth size leading to failed guidance for the erupting canine.

While lateral incisors adjacent to impacted canines were not significantly smaller mesiodistally than the contralateral controls, there were significant differences in the incisogingival height of the crowns. Lateral incisors adjacent to PDCs were 0.45mm shorter relative to their contralateral isomers. Liuk et al.[38] found similar results, showing that the incisoapical length of lateral incisors with an adjacent PDC was 2.0mm shorter than controls. The incisogingival measurements recorded in the present study suggest that a portion of that difference (nearly half of a millimeter) can be found in the height of the crown, likely translating to a larger discrepancy when including the root of the tooth. Most impaction studies to date have evaluated the lateral incisors in terms of their mesiodistal dimensions, seeking to show whether or not the size of the crown is associated with the ability of the canine to erupt as detailed in the guidance theory. However, since it is the root of the lateral incisor which serves as either a guide or a barrier in this theory, it seems more logical to examine the incisoapical dimension of these teeth as a more significant influence for impaction. Although the root length was not measured in this study, the incisogingival findings tend to agree with Liuk et al.[38] that incisors adjacent to PDC are shorter.

The results of this study contribute to the current understanding of canine impaction by showing statistically significant size differences between unilateral PDC and non-impacted teeth and their adjacent incisors. Considering that the voxel size ranged from 0.2-0.4mm per side, the significant differences between the PDC group and the control group only barely approached the width of a single voxel. Despite the small difference between the two groups, the variance in mesiodistal dimension as well as the total crown volume was consistent enough to produce a high level of statistical significance. However, the magnitude of the differences between groups is unlikely to play a primary causative role in the impaction of maxillary canines. The conclusions drawn from this paper are also only applicable when comparing unilateral impactions to their isomers, and not when comparing individuals with impaction to those without. The differences between the complete dentition of groups of patients with and without PDC may be more substantial than the small differences found between contralateral canines in the same patient. If differences are, in fact, generalizable to the dentition as a whole, it would support the theory that impaction is directly or secondarily related to a genetic predisposition for smaller teeth. This potential predisposition does not preclude the possibility that there is a failure of guided eruption from the lateral incisor in cases of canine impaction, and the two theories should not be considered mutually exclusive. If lateral incisors adjacent to impacted canines are significantly shorter incisoapically (whether by genetic propensity or by chance-altered development), it would likewise support the theory of lateral incisor guidance. This study found no differences that were compelling enough to suggest that either the guidance theory or the genetic theory alone more accurately represented the etiology of canine

impaction. It seems likely instead that the etiology is multifactorial, encompassing both genetic

and environmental influences.

Conclusions

1. Unilateral palatally impacted maxillary canine crowns were slightly wider and larger in

   volume than their non-impacted isomers.

2. Lateral incisor crowns adjacent to impacted canines were shorter than those adjacent to non-

   impacted canines.

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Vita

Joseph Eliason was born on May 2, 1985 in Newton, Massachusetts to G. Michael Eliason and Kimberly Ayers. He moved with his family to California when his father was transferred to the Travis Air Force Base near the city of Fairfield. He graduated from Tokay High School in Lodi, California and went on to study biology at Brigham Young University in Provo, Utah. He spent two years serving as a religious missionary for his church in Northern Brazil before graduating in 2009 with his Bachelor of Science degree. Following his undergraduate studies, he attended the University of California, San Francisco School of Dentistry where he was awarded his Doctorate of Dental Surgery in 2013. He subsequently completed a residency in orthodontics at the Virginia Commonwealth University, receiving his Certificate in Orthodontics and a Master of Science in Dentistry degree in 2015. Upon graduation, he will enter private practice as an orthodontic specialist in Northern California.