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Transverse analysis of cone-beam computed tomography (CBCT) at the canine level

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TRANSVERSE ANALYSIS OF CONE-BEAM COMPUTED TOMOGRAPHY (CBCT) AT THE CANINE LEVEL

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DEDICATION

This work is dedicated to my parents, my wife Arwa, and my daughters Jana and Lana.
ACKNOWLEDGMENTS

First and foremost, I would like to thank God for giving me the will and strength throughout this journey, and for all his blessings. I’ve been blessed by having a wonderful life, a supporting and loving family, and great mentors, who helped me and guided me through this trip to earn my masters degree.

A special thanks to Dr. Leslie Will for accepting me into the program, allowing me to join the wonderful world of Orthodontics, and for her infinite patience and support along the way.

I would also like to thank Dr. Matthew Miner and Dr. Melih Motro for mentoring me on this research project, for their guidance and help throughout the process.

This work would never see the light without my parents, who have been an unparalleled source of encouragement and inspiration since my childhood and throughout my life. I want to give you both a special thank you for providing a nurturing and supportive environment and a multidimensional education that allowed me to grow and mature as a person and in my career. Throughout my life you have actively encouraged me and supported me to realize my potentials.

I also lovingly want to acknowledge my wife Arwa, who deserves an honorary degree for being an amazing and patient partner as well as being an essential part of this project. A very special thank you for your unconditional support as I managed my duties as a husband and father with the competing demands of work, study, and personal development. Your love has guided me through the many ups and down of my life. I am tremendously appreciative of your willingness to accompany me on this journey of life, one that we knew would be immensely challenging.

Lastly, a very special thanks for my angels, my daughters Jana and Lana, for being wonderful children and for always finding a way to make me smile no matter how busy or tired I might be.
TRANSVERSE ANALYSIS OF CONE-BEAM COMPUTED TOMOGRAPHY (CBCT) AT THE CANINE LEVEL

GHASSAN A. AL-TURKI

Boston University, Henry M. Goldman School of Dental Medicine, 2016

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ABSTRACT

Objective: To determine the range of positions and relationships between the maxillary and mandibular canines and the related skeleton, and to evaluate using CBCT imaging whether dental and skeletal transverse discrepancies identified in the molar area also exist in the canine area.

Methods: CBCT scans of 148 patients, with and without crossbite were analyzed to assess the width of the jaws and the inclination of the canines relative to the occlusal plane. The dental and skeletal measurements were compared between the non-crossbite and the crossbite groups.
**Results:** At the canine area, we found no statistically significant differences between the non-crossbite group and the crossbite group in canine transverse angulations and maxillary and mandibular width. There is a weak statistically significant correlation between canine lingual width and both maxillary and mandibular canine axial angles that is not observed between canine palatal width and both maxillary and mandibular canine axial angles. We found a weak statistically significant correlation between maxillary canine and molar angulations as well as palatal and lingual width, but not between mandibular canine and molar angulations.

**Conclusion:** We have developed a reliable method to measure transverse tooth angulation and skeletal width using CBCT at the canine level. Changes in transverse angulation and compensation observed in the molar area do not carry on at the canine area. Expansion of crossbite cases are most likely needed at the molar area, as our findings suggest that crossbites are more confined to the molar area and less expressed at the canine level.
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REVIEW OF THE LITERATURE

Lateral cephalometric head films have been widely used for the diagnosis and treatment planning of orthodontic cases using different analyses based on different normal values. However, there is not much utilization of the posteroanterior cephalogram.

The underutilization of the posteroanterior cephalogram could be explained by the effect the following factors may have on any analysis designed for such film. First, landmark identifications are very difficult to accurately locate due to superimposition of the cranial structures in the posteroanterior view (Major et al., 1994; Thurow, 1951). Second, head position during the x-ray exposure plays an important role in landmark identification. Any tilting or rotation of the head can affect the horizontal relationship of the landmarks, making any horizontal measurements and the assessment of symmetry very difficult (Major et al., 1996). Finally, landmarks closer to the posteroanterior porionion axis are more reliable and have fewer variations in transverse dimension evaluation than landmarks located farther from the posteroanterior porionion axis (Ghafari et al., 1995).

Several methods have been developed for the analysis of the craniofacial skeleton as far as shape, size, morphology, and symmetry using posteroanterior
cephalogram despite all the film’s limitations (Ricketts, 1981; Svanholt and Solow, 1977; Grummons and Kappeyne van de Coppello, 1987). The widths between the right and left jugale points and between the right and left antegonial points have been widely used in assessing transverse skeletal discrepancies (Ricketts, 1981). However, only 50% of the variance of the outcome could be accounted for by the correlation between these points, making the jugale point to the antegonial point ratio not such a reliable indicator for transverse relationships (Ghafari et al., 1995). Knowing these limitations makes using posteroanterior cephalograms very challenging.

Many of the limitations and inherent errors associated with 2-dimensional imaging, especially in posteroanterior cephalograms, can be overcome by cone beam computed tomography (CBCT) scans. CBCT in dentistry has provided an imaging solution with no projection errors associated with magnification and no superimposition problems associated with traditional cephalometric imaging and analysis (Hassan et al., 2009). Using CBCT images, accurate analysis of skeletal discrepancies, asymmetries, condylar pathology, and airway patency, can be easily achieved in comparison to standard 2-dimensional radiographs (McNamara and Kapila, 2005; Mah and Hatcher, 2003; Huang et al., 2005; Cevidanes et al., 2006). Studies have shown that 3-dimensional measurements from CBCT scans are closer to anatomic measurements than are traditional 2-
dimensional measurements (Lascala et al., 2004; Lamichane et al., 2009).

Posterior crossbite is one of the most prevalent malocclusions in the deciduous and mixed dentition. It is defined as any abnormal buccolingual relation between opposing molars, premolars, or both in centric occlusion (Kutin and Hawes, 1969). Studies report the frequency of posterior crossbite to range between 7% to 22% of the population (Sidlauskas and Lopatiene, 2009; Troelstrup and Moller, 1979; Helm, 1968; Foster and Hamilton, 1969; Day and Foster, 1971; Thilander and Myrberg, 1973; Egermark-Eriksson et al., 1990; Kerosuo, H, et al., 1991); adding edge-to-edge transverse discrepancy to the definition would significantly increase these percentages (Kurol and Bergland, 1992). The most prevalent form of crossbite accounting for 80% to 97% of all the cases is a unilateral crossbite with a functional shift of the mandible toward the crossbite side (Kutin and Hawes, 1969; Sidlauskas and Lopatiene, 2009; Thilander, 1984). In skeletal crossbite cases there is usually a discrepancy in the transverse dimension between the maxillary and mandibular arches, resulting in either a unilateral or bilateral posterior crossbite. This could be due to a narrow maxilla and normal mandible, a normal maxilla and wide mandible, or a narrow maxilla and wide mandible (Betts and Vanarsdall, 1995). On the other hand, dental crossbites involving a single tooth are usually due to arch length
deficiency, an over retained primary tooth, or abnormal eruption pattern. (Kutin and Hawes, 1969).

The literature shows that the etiology of posterior crossbite is multifactorial, including dental, skeletal, and neuromuscular. Although the amount of effect each factor has is not clear, constriction or reduction in the transverse dimension of the maxillary arch was suggested to be the most frequent cause, which could be due to finger sucking, low tongue posture, certain swallowing habits, or mouth breathing resulting from obstruction of upper airways (Thilander, 1984; Melsen et al., 1979; Linder-Aronson, 1970; Hannuksela and Vaananen, 1987; Melink et al., 2010). A study observing 3 year old children found an association between pacifier use and an increase in mandibular intercanine width, a decrease in maxillary intercanine width, and an increase incidence of posterior crossbite (Ogaard et al., 1994). Other studies of similar age-groups had similar results, showing that non-nutritive sucking habits, such as prolonged digit and pacifiers sucking, especially after the age 4, are strongly associated with the development of posterior crossbite (Adair, et al., 1995; Lindner and Modeer, 1989; Warren and Bishara, 2002). Some of the environmental factors that could result in a small maxilla to mandible width ratio, correlating with a significantly higher prevalence of posterior crossbite, include hypertrophied adenoids or tonsils and allergic rhinitis leading to upper
airway obstruction and mouth breathing (Oulis et al., 1989; Kerr et al. 1989; Bresolin et al., 1983).

A study by Kutin and Hawes of 515 children between the age of 3 to 9 years, in which 40 of them had posterior crossbite in the deciduous or mixed dentition, found that around 92% of crossbites that were not treated in the deciduous dentition were followed by crossbites in the mixed dentition. They stated that treatment of crossbites in the deciduous dentition favors development of normal transverse occlusion in the mixed dentition, and that there is little self-correction in posterior crossbites to justify no intervention (Kutin and Hawes, 1969). Another study confirmed the previous finding and added that initiation of early treatment would increase the chances of having normal transverse first molar relation in permanent dentition. They explained that the longer a crossbite is present, the longer the inhibition of transverse growth of the maxilla on the affected side and the longer the musculature will have to adjust to the situation (Schroder and Schroder, 1984).

Studies show that the temporomandibular joint (TMJ) can be affected by posterior crossbites. On the crossbite side the condyles are in a superior and posterior position in the glenoid fossa, while on the non-crossbite side they are in an anterior and inferior position (Hesse, et al., 1997). Asymmetric mandibular
growth, facial disharmony, and several functional changes in the masticatory muscles and TMJ could be sequelae of the neuromuscular adaptation of the acquired mandibular position (Sonnesen et al., 1998; Bishara et al., 1994; O'Bryn et al., 1995; Egermark et al., 2005). Vanderas and Papagiannoulis studied the relationship between the different types of morphologic and functional occlusion and the signs and symptoms of TMD, they found a significant impact on TMJ tenderness as associated with deviation of the mandible on opening in patients with posterior crossbite (Vanderas and Papagiannoulis, 2002). Sonnesen et al. found that children with unilateral crossbite experience more tenderness in the anterior temporalis and superficial masseter muscles as well as several headaches per week (Sonnesen et al., 1998). However, other studies could not find a causal relationship between TMD signs and symptoms and posterior crossbite (Sari et al., 1999). Having a crossbite could be considered a cofactor in identifying patients with TMD, and further highlights the importance of early treatment of crossbites (Egermark-Eriksson et al., 1990).

Studies have found an association between posterior crossbite and asymmetrical muscular functioning at rest, and during chewing or clenching (Troelstrup and Moller, 1970; Ingervall and Thilander, 1975; Michler, 1987; Andrade et al., 2007). Kecik et al. showed a significant difference between subjects with crossbites and control groups in anterior temporalis and master
muscle activity at rest position. Additionally, where there is higher muscle activity on the crossbite side, the difference was eliminated after maxillary expansion (Kecik, 2007).

Maximal occlusal force is considered an important predictor for masticatory performance, as it is linked to high masticatory performance, especially when chewing hard foods (Okiyama et al., 2003). A change in occlusal forces can be observed in patients with posterior crossbites, because the anterior temporalis muscle is more active and the masseter is less active on the crossbite side than on the non-crossbite side (Sonnesen et al., 1998). In a systematic review by Andrade et al., they found that children with posterior crossbites have fewer numbers of teeth in contact as well as a reduced maximal bite force. However, there is no significant difference in bite force values between children with and without posterior unilateral crossbite in the primary dentition unlike the different force values found in the early mixed dentition (Andrade et al., 2009; Rentes et al., 2002; Castela et al., 2007).

Miner et al. used CBCT in the analysis of the transverse dimension. They developed a transverse analysis using CBCT scans, and came up with a range of normal positions and relationship between the maxillary and mandibular molars and its related skeleton. Within the clinical non-crossbite group, a significant
number of patients were revealed to have skeletal transverse jaw discrepancy that had been masked by dental compensation. In addition, they derived normative values for the skeletal and dental measurements for the CBCT transverse analysis from the control group, which was defined by having molar inclinations of all first molars within one standard deviation above or below the mean of the non-crossbite group. They concluded that skeletally, both the bilateral and unilateral crossbite groups had narrower maxillary widths than did the controls, but also wider mandibles, particularly with more severe bilateral crossbites. Dentally, the unilateral crossbite group had more upright teeth on the non-crossbite side. In the non-crossbite groups with dental compensations, the superior convergent and inferior convergent differences in both dental and skeletal characteristics were marked. Patients without crossbites can have significant discrepancies that might warrant treatment (Miner et al., 2012).

The purpose of this study was to continue the work of Miner et al., by examining if their observations at the molar level carry on in the canine area as far as skeletal width and tooth angulation using cone-beam CT imaging, and determine the range of positions and relationships between the maxillary and mandibular canines and the related skeleton.
AIM AND OBJECTIVES

Aim:
The aim of this study was to explore the relationship between dental and skeletal transverse discrepancies at the canine level.

Objectives:
The objective of this study was to determine the range of positions and relationships between the maxillary and mandibular canines and the related skeleton, and to evaluate if the canines follow the molars as far as skeletal width and tooth angulation using cone beam CT imaging.

MATERIAL AND METHODS

The data from Miner et al. was used for this study. The cone beam CT scans of 2279 patients taken in centric relation at the time of initial orthodontic records at two private orthodontic offices were reviewed retrospectively. The institutional review board of Boston University reviewed and approved the consent forms, study protocols, and affiliation agreements with the practices before data collection. Each patient had a 20-second CBCT scan performed on an
i-CAT scanner (17cm (h) x 23cm (d)) (i-CAT Classic Imaging Sciences International, Hatfield, Pa) with a voxel size of 0.4 mm. From the 2279 patients, 241 met the inclusion criteria for the study by Miner et al.

**Selection Criteria**

Our study included 148 patients who met the following criteria: (1) Mixed or permanent dentition and erupted maxillary and mandibular first permanent molars and canines in bilateral Angle Class I relationships. (2) Class I intercuspation of the posterior occlusion and Class I canines. (3) No missing teeth other than third molars. (4) Crowding of no more than 4mm. (5) No overjet or overbite of more than 4mm. (6) No crowns or cuspal restorations. (7) No previous orthodontic treatment. (8) No history of craniofacial trauma or surgery. (9) No temporomandibular joint pain.

Using Dolphin software Version 10.5 (Dolphin Imaging Sciences, Chatsworth, Calif) Miner et al. used the following reference planes to ensure that the 2-dimensional coronal slices were consistently oriented (Figure 1): (1) The axial plane was defined as the functional occlusal plane. (2) The coronal plane was perpendicular to the axial plane, passing through the buccal groove of the maxillary right first molar. (3) The sagittal plane was perpendicular to both the axial and coronal planes, passing through the midpoint between the medial rims of the orbits. They used coronal cross-sections (5-mm thickness) through the
middle of the maxillary and mandibular first molar crowns. The mesial root of the mandibular first molar and the mesiobuccal root of the maxillary first molar were used to determine the long axis of the tooth. Five-millimeter slices were used so that both the mesiobuccal and palatal root of the maxillary first molar could be visualized on the same section to minimize error in identification of the furcation. (Table 1) shows the dental and skeletal landmarks and parameters as defined by Miner, et al.

Figure 1. Scan orientation and linear and angular measurements by Miner et al.
Table 1. Dental and skeletal landmarks and parameters as defined by Miner, et al.

<table>
<thead>
<tr>
<th>Landmark or parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long axis, maxillary molar</td>
<td>The line drawn between the deepest concavity between the buccal and palatal cusps and the furcation of the roots.</td>
</tr>
<tr>
<td>Long axis, mandibular molar</td>
<td>The line drawn between the deepest concavity between the buccal and lingual cusps and the root apex.</td>
</tr>
<tr>
<td>Functional occlusal plane</td>
<td>The line drawn between the points of contact between the maxillary and mandibular molars</td>
</tr>
<tr>
<td>Molar Palatal S point</td>
<td>The point on the palatal cortex of the maxilla at a vertical level halfway between the buccal alveolar crest and the buccal root apex of the maxillary first molar.</td>
</tr>
<tr>
<td>Molar Lingual S point</td>
<td>The point on the lingual cortex of the mandible at a vertical level halfway between the buccal alveolar crest and the apex of the mandibular first molar.</td>
</tr>
</tbody>
</table>

The subjects were then divided into crossbite and control groups based on the presence or absence of unilateral or bilateral posterior crossbite involving two or more teeth per side. Miner et al. preliminary analysis of the original non-crossbite group showed high variability in all linear and angular measurements. They found that the non-crossbite group included patients who had apparently normal skeletal and dental transverse relationships, but also patients with an obvious skeletal transverse discrepancy between the maxilla and the mandible that had been masked by dental tipping either buccally or lingually (dental compensation). They divided the non-crossbite group to 3 groups (Figure 2),
with the total sample including 5 groups (control, superior convergent, inferior convergent, unilateral crossbite, and bilateral crossbite) (Miner et al., 2012).

**Figure 2. Dental compensation in the non-crossbite group as presented by Miner et al.**

![Diagram of dental compensation](image)

A, Control group; B, superior convergent group; C, inferior convergent group.

**Patient Demographics**

Using a desired statistical power level of 0.8 and a probability level of 0.05, the power analysis revealed that we need a minimum of 9 subjects per group for a two-tailed hypothesis. Using data from Miner et al. our sample included 148 patients (83 females and 65 males) who met the inclusion criteria. The mean age was $13.9 \pm 1.3$ years old, the females were $13.8 \pm 1.4$ years and the males were $13.9 \pm 1.3$ years. The total sample included 125 patients without crossbites and 23 with crossbite, either unilateral or bilateral (Table 2). When dividing the sample
in the same manner as Miner et al., we found 61 controls, 25 in the superior convergent group, 39 in the inferior convergent group, 9 with a unilateral crossbite, and 14 with bilateral crossbites. For all unilateral crossbite subjects, we used the right side as the crossbite side and the left side as the non-crossbite. (Table 3) shows the age and gender distribution among the groups.

Table 2. Subject demographics.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age (mean ± SD)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-crossbite</td>
<td>125</td>
<td>13.9 ± 1.3</td>
<td>72</td>
<td>53</td>
</tr>
<tr>
<td>Crossbite</td>
<td>23</td>
<td>13.8 ± 1.6</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 3. Age and gender distribution among the groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age (mean ± SD)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>61</td>
<td>13.9 ± 1.4</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>Superior convergent</td>
<td>25</td>
<td>13.6 ± 1.3</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Inferior convergent</td>
<td>39</td>
<td>14.0 ± 1.3</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Unilateral crossbite</td>
<td>9</td>
<td>14.2 ± 1.4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Bilateral crossbite</td>
<td>14</td>
<td>13.9 ± 1.3</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>
Scan Analysis

CBCT scans were imported into Dolphin Imaging Premium Version 11.5.04.36 (Dolphin Imaging Sciences, Chatsworth, California) in 3-D DICOM-3 file format. The scans were initially oriented in the same manner as Miner et al.; however, this orientation was challenging. Once the scan was oriented, it was hard to capture the full length of the canine due to its location on the curvature of the dental arch and the distal orientation of the root tip. In order to capture the full length we would have wide slices with other teeth overlapping the cut making our linear and angular measurements difficult (Figure 3).

In order to overcome these challenges and obtain the most accurate and reproducible measurements, we modified the scan orientation. Once the scan was oriented in the same manner as Miner et al., the scan was rotated in an upward or downward direction around the coronal plain. This modification gave us two cuts, one for the maxillary canines and another for the mandibular canines. For the maxillary canines, once the scan was initially oriented, it was then rotated downwards around the coronal plane and the full length of the canines was perpendicular to the initial coronal plane (Figure 4). For the mandibular canines, the scans were rotated upwards around the coronal plane (Figure 5).
Figure 3. Using scan orientation by Miner et al. showing the difficulty of canine linear and angular measurements.
Figure 4. Modification of the scan orientation for the maxillary canines and the maxillary canine linear and angular measurements.
Figure 5. Modification of the scan orientation for the mandibular canines and the mandibular canine linear and angular measurements.
In order to perform our transverse measurements, we used the dental and skeletal landmarks presented in (Table 4). Our linear and angular measurements included: the Canine Palatal S Width, defined as the distance between points on the left and right palatal cortex of the maxilla at the level of the CEJ of the maxillary canine; the canine lingual S width, defined as the distance between points on left and right side of the lingual cortex of the mandible at the level of the CEJ of the mandibular canine; canine maxillomandibular width difference, defined as the difference between palatal width and lingual width. Transverse canine angulation measurements were made by creating an occlusal plane reference between the canine cusp tips and then measuring the angle to the line drawn down the long axis of the tooth. For both maxillary and mandibular canines, the line was drawn between the cusp tip and the root apex of the respective canine. The angle formed between the long axes of the maxillary and mandibular canine was then recorded as transverse canine angulation.
Table 4. Canine dental and skeletal landmarks and parameters.

<table>
<thead>
<tr>
<th>Landmark or parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long axis, maxillary canine</td>
<td>The line drawn between the cusp tip and the root apex of the maxillary canine.</td>
</tr>
<tr>
<td>Long axis, mandibular canine</td>
<td>The line drawn between the cusp tip and the root apex of the mandibular canine.</td>
</tr>
<tr>
<td>Canine Palatal S point</td>
<td>The point on the palatal cortex of the maxilla at the level of the CEJ of the maxillary canine.</td>
</tr>
<tr>
<td>Canine Lingual S point</td>
<td>The point on the lingual cortex of the mandible at the level of the CEJ of the mandibular canine.</td>
</tr>
</tbody>
</table>

Statistical Analysis

To reduce measurement errors, 20 CBCTs were randomly selected to be re-measured by the same principal investigator (GA) one month after the first measurements. The intra-examiner and inter-examiner reliability of the measurements was assessed using Intra-class Correlation Coefficient. Power analysis was also performed based on the sample size we were able to obtain.

Standard descriptive statistics included means and standard deviations as well as frequencies for the measured variables. Bivariate analysis included t-test, ANOVA, and Pearson’s correlation. All statistical analysis was performed using IBM SPSS statistical software version 20, at $\alpha = 0.05$ level of significance.
RESULTS

The Intra-class Correlation Coefficient showed that intra-examiner and inter-examiner agreement was reliable (Mean, 94%; Range, 92%-96%) and (Mean, 89%; Range, 86%-92%) respectively, for the angular and linear measurements chosen. Power analysis revealed that based on our sample size, the power of our study was confirmed at 0.8.

None of the patients had a clinical crossbite at the canine area. No statistically significant difference was observed between the non-crossbite group and the crossbite group in maxillary canine axial angles, mandibular canine axial angles, canine palatal and lingual widths, and canine maxillomandibular width difference (Table 5). However, at the molar level, we found a statistically significant difference between the non-crossbite group and the crossbite group in right maxillary and mandibular molar axial angles, with the non-crossbite group having larger angles. We did not find a statistically significant difference between the non-crossbite group and the crossbite group in the left maxillary and mandibular molar axial angles. We found a statistically significant difference between the non-crossbite group and the crossbite group in molar palatal and lingual widths, as well as molar maxillomandibular width difference, with the
crossbite group showing narrower maxillas, wider mandibles, and larger maxillomandibular width differences (Table 6).

When examining the correlation between the canine and molar area in transverse tooth angulation and skeletal width, we found a weak positive statistically significant correlation between maxillary canine and molar angulations. Furthermore, we found a weak positive statistically significant correlation between canine palatal and lingual width and molar palatal and lingual width. No statistically significant correlation between mandibular canine and transverse molar angulation was observed (Table 7). When examining the correlation between canine skeletal width and canine angulation, there was a weak positive statistically significant correlation between canine lingual width and both maxillary and mandibular canine axial angles. There was also a weak negative statistically significant correlation between the canine maxillomandibular width difference and the mandibular canine axial angles. No statistically significant correlation was observed between the canine maxillomandibular width difference and the maxillary canine axial angles. There was no statistically significant correlation between canine palatal width and both maxillary and mandibular canine axial angles (Table 8). When examining the correlation between molar area skeletal width and molar angulation, there was a weak negative statistically significant correlation between molar palatal width
and both maxillary and mandibular molar axial angles. There was a weak positive statistically significant correlation between molar lingual width and both maxillary and mandibular molar axial angles. There was a weak negative statistically significant correlation between molar maxillomandibular width difference and both maxillary and mandibular molar axial angles (Table 9).

No statistically significant difference was observed between the control, superior convergent, inferior convergent, unilateral crossbite, and bilateral crossbite groups in maxillary canine axial angles, mandibular canine axial angles, canine palatal and lingual widths, and canine maxillomandibular width difference (Table 10).

Table 5. Comparison of canine linear and angular measurements between the crossbite and non-crossbite groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-crossbite (mean ± SD)</th>
<th>Crossbite (mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right canine axial angle</td>
<td>81.3 ± 4.5</td>
<td>80.7 ± 6.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Maxillary left canine axial angle</td>
<td>80.3 ± 4.4</td>
<td>82.2 ± 7.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Mandibular right canine axial angle</td>
<td>84.2 ± 4.8</td>
<td>86.3 ± 6.3</td>
<td>0.06</td>
</tr>
<tr>
<td>Mandibular left canine axial angle</td>
<td>85.1 ± 4.7</td>
<td>86.8 ± 4.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Canine Palatal S Width</td>
<td>22.9 ± 1.9</td>
<td>23.4 ± 2.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Canine Lingual S Width</td>
<td>18.3 ± 1.7</td>
<td>19.2 ± 1.8</td>
<td>0.06</td>
</tr>
<tr>
<td>Canine Maxillomandibular width difference</td>
<td>4.6 ± 1.6</td>
<td>4.4 ± 1.7</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Table 6. Comparison of molar linear and angular measurements between the crossbite and non-crossbite groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-crossbite (mean ± SD)</th>
<th>Crossbite (mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right molar axial angle</td>
<td>96.8 ± 4.5</td>
<td>94.7 ± 5.1</td>
<td>0.04</td>
</tr>
<tr>
<td>Maxillary left molar axial angle</td>
<td>97.5 ± 3.9</td>
<td>98.2 ± 7.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Mandibular right molar axial angle</td>
<td>104.4 ± 4.5</td>
<td>101.1 ± 7.0</td>
<td>0.03</td>
</tr>
<tr>
<td>Mandibular left molar axial angle</td>
<td>104.2 ± 4.1</td>
<td>104.9 ± 7.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Molar Palatal S Width</td>
<td>28.1 ± 2.4</td>
<td>25.9 ± 2.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Molar Lingual S Width</td>
<td>29.0 ± 2.8</td>
<td>31.6 ± 4.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Molar Maxillomandibular width difference</td>
<td>-0.8 ± 3.3</td>
<td>-5.7 ± 5.7</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 7. Correlation between the canine and molar tooth angulation and skeletal width

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right canine axial angle / Maxillary right molar axial angle</td>
<td>0.2</td>
<td>0.03</td>
</tr>
<tr>
<td>Maxillary left canine axial angle / Maxillary left molar axial angle</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Mandibular right canine axial angle / Mandibular right molar axial angle</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Mandibular left canine axial angle / Mandibular left molar axial angle</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Canine Palatal S Width / Molar Palatal S Width</td>
<td>0.3</td>
<td>0.003</td>
</tr>
<tr>
<td>Canine Lingual S Width / Molar Lingual S Width</td>
<td>0.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Canine Maxillomandibular width difference / Molar Maxillomandibular width difference</td>
<td>0.2</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Table 8. Correlation between canine area skeletal width and canine angulation

<table>
<thead>
<tr>
<th></th>
<th>Canine Palatal S Width</th>
<th>Canine Lingual S Width</th>
<th>Canine Maxillomandibular width difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right canine axial angle</td>
<td>0.1</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Maxillary left canine axial angle</td>
<td>0.2</td>
<td>0.06</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mandibular right canine axial angle</td>
<td>0.1</td>
<td>0.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mandibular left canine axial angle</td>
<td>0.1</td>
<td>0.2</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 9. Correlation between molar area skeletal width and molar angulation.

<table>
<thead>
<tr>
<th></th>
<th>Molar Palatal S Width</th>
<th>Molar Lingual S Width</th>
<th>Molar Maxillomandibular width difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right molar axial angle</td>
<td>-0.3</td>
<td>0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>Maxillary left molar axial angle</td>
<td>-0.4</td>
<td>0.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>Mandibular right molar axial angle</td>
<td>-0.3</td>
<td>0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>Mandibular left molar axial angle</td>
<td>-0.4</td>
<td>0.2</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

Table 10. Comparison of linear and angular canine measurements between the groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (mean ± SD)</th>
<th>Superior convergent (mean ± SD)</th>
<th>Inferior convergent (mean ± SD)</th>
<th>Unilateral crossbite (mean ± SD)</th>
<th>Bilateral crossbite (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary right canine axial angle</td>
<td>80.4 ± 4.9</td>
<td>81.6 ± 4.9</td>
<td>81.6 ± 4.9</td>
<td>82.9 ± 5.4</td>
<td>82.2 ± 4.6</td>
</tr>
<tr>
<td>Maxillary left canine axial angle</td>
<td>80.1 ± 5.4</td>
<td>82.2 ± 4.9</td>
<td>80.5 ± 3.9</td>
<td>81.1 ± 6.2</td>
<td>80.8 ± 4.3</td>
</tr>
<tr>
<td>Mandibular right canine axial angle</td>
<td>84.4 ± 4.9</td>
<td>83.8 ± 5.7</td>
<td>85.5 ± 4.9</td>
<td>86.2 ± 6.9</td>
<td>85.7 ± 4.6</td>
</tr>
<tr>
<td>Mandibular left canine axial angle</td>
<td>84.9 ± 4.6</td>
<td>84.7 ± 4.0</td>
<td>86.4 ± 4.9</td>
<td>86.0 ± 6.6</td>
<td>85.8 ± 5.0</td>
</tr>
<tr>
<td>Canine Palatal S Width</td>
<td>23.1 ± 2.0</td>
<td>23.2 ± 2.0</td>
<td>23.0 ± 2.0</td>
<td>23.3 ± 1.9</td>
<td>22.4 ± 1.8</td>
</tr>
<tr>
<td>Canine Lingual S Width</td>
<td>18.2 ± 1.7</td>
<td>18.7 ± 1.7</td>
<td>18.7 ± 1.8</td>
<td>18.9 ± 2.2</td>
<td>18.2 ± 1.7</td>
</tr>
<tr>
<td>Canine Maxillomandibular width difference</td>
<td>4.9 ± 1.8</td>
<td>4.5 ± 1.4</td>
<td>4.2 ± 1.6</td>
<td>4.4 ± 1.7</td>
<td>4.2 ± 1.3</td>
</tr>
</tbody>
</table>
DISCUSSION

It is agreed upon that maxillofacial deformities and malocclusions require diagnosis in all 3-planes of space (Ghafari et al., 1995; Grummons and Kappeyne van de Coppello, 1987; Broadbent, 1931; Bergman, 1988; Thurow, 1981; Maki et al., 2003). By using 3-dimensional imaging in orthodontics, it is relatively easy to obtain a diagnosis in 3-plains of space with minimal radiation. The use of CBCT overcomes the limitations of 2-dimensional imaging especially in posteroanterior cephalograms. There is no overlap of the molars and other structures, making it easy to determine teeth and alveolar inclinations by viewing coronal cuts at different depths (Maki et al., 2003).

While there is no agreement on the best timing for orthodontic treatment of many occlusal problems, it is generally accepted that posterior crossbite should be treated as early as possible in order to avoid deleterious effects on the growth and development of the stomatognathic system (Kutin and Hawes, 1969; Troelstrup and Moller, 1970; Schroder and Schroder, 1984; Andrade and Gameiro, 2009; Ingervall and Thilander, 1975; Andrade et al., 2009; Profitt, 2000; Clifford, 1971; McNamara, 2002).

The objective of this study was to determine the range of positions and relationships between the maxillary and mandibular canines and the related
skeleton, and to evaluate if the canines correspond to the molars as far as skeletal width and tooth angulation using cone beam CT imaging.

In our sample, none of the patients had a clinical crossbite at the canine area even though some had clinical molar crossbites. We found no statistically significant difference between the non-crossbite group and the crossbite group regarding transverse canine angulation and maxillary and mandibular width at the canine area. On the other hand, at the molar level, we found a statistically significant difference between the non-crossbite group and the crossbite group in arch width at the level of the molar. The crossbite group had narrower maxillas and wider mandibles, which is in agreement with the results of Miner et al. (Miner et al., 2012). We found a statistically significant difference between the non-crossbite group and the crossbite group in the right maxillary and mandibular molar axial angles, with the crossbite group showing smaller angles. However, this was not observed on the left side. This is not in agreement with of Miner et al. (Miner et al., 2012) this could be explained by the fact that in order to have an adequate sample size in each group for comparison, we pooled all the groups (control, superior convergent, inferior convergent, unilateral crossbite, and bilateral crossbite) into 2 groups only (non-crossbite and crossbite).

When examining the differences between the control, superior convergent, inferior convergent, unilateral crossbite, and bilateral crossbite groups at the
canine level, we found no statistically significant difference in maxillary canine axial angles, mandibular canine axial angles, canine palatal and lingual widths, and canine maxillomandibular width difference. This suggests that the differences observed between the groups at the molar area by Miner et al. is not present at the canine level.

When examining the correlation of teeth angulations and skeletal width between the canine and molar area, we found a weak positive statistically significant correlation between maxillary canine and molar angulations, but not between mandibular canine and molar angulations. We also found a weak positive statistically significant correlation between palatal and lingual width, and maxillomandibular width difference at the canine and molar level.

When examining the relationship between teeth angulations and the related skeleton width we found that, at the canine level there was a weak positive statistically significant correlation between canine lingual width and both maxillary and mandibular canine axial angles, but this was not observed between canine palatal width and both maxillary and mandibular canine axial angles. At the molar level, there was a weak negative statistically significant correlation between molar palatal width and both maxillary and mandibular molar axial angles, while there was a weak positive statistically significant
correlation between molar lingual width and both maxillary and mandibular
molar axial angles.

Bishara et al. found that in the maxillary arch, intercanine width increases
between 3 and 13 years by 6 mm but decreases by 1.7 mm between 13 and 45
years. On the other hand, intermolar width increases by 2 mm between 3 and 5
years and by 2.2 mm between 8 and 13 years but decreases by 1 mm by 45 years
of age. In the mandibular arch, intercanine width increases between 3 and 13
years by 3.7 mm but decreases by 1.2 mm between 13 and 45 years. Intermolar
width increases by 1.5 mm between 3 and 5 years and by 1 mm between 8 and 13
years but decreases by 1 mm by 45 years of age. On average, after the eruption of
the four incisors around the age of 8 years, the mandibular intercanine width is
established and no or a slight decrease in arch widths is expected (Bishara et al.,
1997). In a review by Lee, he showed that the lower intercanine width increases
significantly in the mixed dentition but not in the permanent dentition after 12
years of age and the upper and lower intermolar widths increase between ages of
7 and 18 especially in males. (Lee, 1999; De Koch, 1972; Sillman, 1964).

As our study was a continuation of the work done by Miner et al., we
faced a challenge in orienting our scans in the same manner. It was difficult
capturing the full length of the canine due to its location on the curvature of the
dental arch and the distal orientation of the root tip. This led us to introduce a modification for the scan orientation. Once the scan was oriented in the same manner as Miner et al., the scan was rotated in an upward or downward direction around the coronal plane. This modification gave us two cuts, one for the maxillary canines and another for the mandibular canines. This method gave us the full length of the canine and was shown to be reliably reproducible. We also had to modify the way we measured the skeletal width, as we used the arch cortex at the level of the CEJ instead of the cortex at a vertical level halfway between the buccal alveolar crest and the apex of the tooth, where the curvature of the dental arch made it difficult. Again this method was shown to be reliably reproducible. Shewinvanakitkul et al. introduced a practical and reliable method to measure buccolingual inclination of mandibular canines and first molars using a line tangent to the inferior border of the mandible and the long axis of the tooth (Shewinvanakitkul et al. 2011). However their method was used only for the mandibular arch and intercanine and intermolar widths were measured on casts.

Our findings suggest that crossbites are more confined to the posterior molar area and not expressed at the canine level. This could be due to our sample size, as it was difficult to find larger groups to confirm the validity of our results. Untreated subjects were difficult to find despite examining more than 2000 patients. It may also indicate that posterior crossbite is a discrepancy that
increases posteriorly and may be best treated using an appropriate expansion device.

Clinically our findings do show that in crossbite cases more expansion is desired in the posterior area. This agrees with the literature showing that arch expansion is more likely to be stable and effective in the posterior region and that it is unlikely to be stable when expansion is done at the canine area, especially in the lower arch unless the canines are displaced lingually by the occlusion (Lee, 1999). When treating different malocclusions no matter the modality, there is 1 to 2 millimeter of mandibular intercanine expansion that tends to relapse to the pretreatment position post retention (Burke et al., 1998).

SUMMARY AND CONCLUSIONS

• We have developed a reliable method to measure transverse tooth angulations and skeletal width using CBCT at the canine level.

• We have found no statistically significant difference between the non-crossbite group and the crossbite group in transverse canine angulation and maxillary and mandibular width at the canine area.
• Changes in transverse angulations and compensation observed in the molar area do not extend to the canines.

• There is a weak positive statistically significant correlation between maxillary canine and molar angulations as well as palatal and lingual width, but not between mandibular canine and molar angulations.

• There is a weak positive statistically significant correlation between canine lingual width and both maxillary and mandibular canine axial angles that is not observed between canine palatal width and both maxillary and mandibular canine axial angles.

• Expansion of crossbite cases are most likely needed at the molar area, as our findings suggest that crossbites are more confined to the posterior molar area and less expressed at the canine level.
REFERENCES


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Educational Qualifications:

2013-Present  Certificate of Advanced Graduate Studies (CAGS) and Masters of Science in Dentistry degree (MSD) in Orthodontics & Dentofacial Orthopedics candidate 2016
Boston University, Goldman School of Dental Medicine, Boston, MA, USA.

2010-2015  Doctorate of Science in Dentistry (DScD) in Dental Public Health
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1997-2003  Bachelor Degree in Dental Medicine & Surgery (BDS) (2nd Honor)
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Clinical and Academic Experience:

2013-Present  Demonstrator (junior faculty member):
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2009-2010  Internship in Oral and Maxillofacial Surgery (OMFS):
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Scientific Research:

2015 **Accepted abstract for oral presentation:** Benign Prostatic Hyperplasia, Prostate Specific Antigen and Periodontal Disease, 2016 AADR/CADR Annual Meeting & Exhibition, Los Angeles, California

2013-Present **Masters Thesis:** Transverse analysis of CBCTs at the canine level

2010-2015 **Doctorate Thesis:** Diseases of the prostate gland, prostate specific antigen and periodontal disease

2007 **Accepted abstract for poster presentation:** Central Giant Cell Granuloma: a case report and review of the literature, 5th Pan Arab Association of Oral Maxillofacial Surgeons Conference, Jeddah, Saudi Arabia.

2005 **Accepted abstract for poster presentation:** Distraction Osteogenesis in Management of Compromised Pediatric Airway, 17th Saudi International Dental Congress, Riyadh, Saudi Arabia.

2003-2004 **Calcified Carotid Artery Atheroma on Panoramic X-Ray.**

2002-2003 **Prevalence of Caries among Orphans in the City of Jeddah, Saudi Arabia.**

Honors and Awards:

2008 **Certificate of Appreciation**
For active participation as an organizer in the 5th Pan Arab Association of Oral Maxillofacial Surgeons Conference, Jeddah, Saudi Arabia.

2008 **Certificate of Appreciation**
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2006 **Certificate of Appreciation**
For participation in the 17th Saudi International Dental Congress with a poster presentation, Riyadh, Saudi Arabia.

2004 **Certificate of Honor**
(Second degree honor), KAU.

2004 **Certificate of Appreciation**
For active participation as an organizer in the 1st Conference of The Faculty of Dentistry on Recent Advances in Clinical Dentistry, KAU, Jeddah, Saudi Arabia.

2002 & 2003 **Certificate of Appreciation**
For active participation in sport activities in the Faculty of Dentistry, KAU.

2002-2004 **Certificate of Appreciation**
For outstanding performance in the plays at the final ceremony of dental students activities, KAU.