A Three Dimensional Assessment of the Treatment Success of Impacted Permanent Maxillary Canines

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THESIS

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LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
CBCT	Cone-Beam Computed Tomography
CT	Computed Tomography
IRB	Institutional Review Board

SUMMARY

The purpose of this study was to evaluate the treatment success of impacted permanent maxillary canines using cone-beam computed tomography. The primary objectives were: 1) to utilize a novel method to localize the precise position of impacted maxillary canines using CBCT images, 2) to quantify the predicted difficulty of each impacted canine, 3) and to compare this experimental group's duration of treatment to control groups.

The treatment group consisted of 17 patients with unilateral or bilateral maxillary canine impaction who had initial and progress CBCT scans taken in a private practice setting. Three planes were constructed on each image using stable skeletal landmarks. Linear and angular measurements were recorded for the initial and progress CBCT images.

The study concludes that the initial vertical distance of the apex was moderately correlated to duration of treatment. The frontal view angle between the long axis of the tooth and sagittal axis was also moderately correlated with both duration of alignment and duration of treatment. Further research is necessary to determine the cause of these findings. The treatment group had significantly shorter treatment duration than all of the canine impaction controls and all but two of the non-impaction controls.

1. INTRODUCTION

1.1. Background

The impaction of permanent maxillary canines is one of the most difficult problems encountered in orthodontics. Patients with impacted canines have longer average durations of orthodontic treatment (Becker and Chaushu, 2003; Fleming et al., 2009; Stewart et al., 2001). Clinicians often face difficulty in many aspects of treating patients with impacted teeth: identifying the precise location of the impacted tooth, devising an appropriate treatment plan, and estimating the correct duration of treatment.

In order to make a proper diagnosis and treatment plan, orthodontists have traditionally depended on the utilization of two-dimensional radiographs. Attempts have been made to use measurements on lateral cephalogram and panoramic radiographs in order to localize impacted teeth and make predictions about the duration of treatment. Traditional 2D radiographs, however, have many inherent weaknesses which lead to error in measurements and the lack of accurate reproducibility (Catic et al., 1998; Lund and Manson, 1975; Xie et al., 1996).

More recently, cone-beam computed tomography has become widely available allowing orthodontists to visualize the maxilla-mandibular complex in three dimensions. As the incorporation of CBCT within orthodontics keeps growing, more studies are needed to evaluate its use in studying impacted canines. The purpose of this study is to evaluate the success and duration of orthodontic treatment of patients with impacted maxillary canines using CBCT images.

1.2 Research Hypotheses

The first hypothesis is that there will be a direct correlation between initial linear measurements of impacted canines to the duration of treatment. The second hypothesis is that there will be a direct correlation between initial angular measurements of impacted canines to the duration of treatment. The third hypothesis is that the duration of treatment for patients with impacted canines treated with SureSmile™ is shorter than duration of treatment for control groups.

2. REVIEW OF LITERATURE

2.1 <u>Prevalence, Etiology, and Sequelae of Impacted Canines</u>

A tooth is considered impacted when there is a delay in its eruption and there is clinical or radiographic evidence showing that future eruption may not take place (Thilander and Jakobsson, 1968). There is controversy in the literature about when normal eruption should occur for each tooth. Becker (2007) proposes that root development should be used as the basis for defining expected eruption times for different teeth. Gron (1962) concluded that under normal circumstances, a tooth will erupt when ¾ of its final root length is developed. Others suggest that eruption should be based on mean eruption ages and argue that delayed eruption occurs when tooth emergence is more than two standard deviations from normal (Rasmussen and Kotsaki, 1997).

The impaction of a maxillary canine is a difficult problem encountered in orthodontics. According to various studies, the prevalence of maxillary canine impaction in adolescents ranges between 0.9 and 5.9% depending on the population examined (Ericson and Kurol, 1986). The majority of studies, however, report the prevalence to be closer to the lower end of this range (Becker, 2007; Ericson and Kurol, 1986). Of patients with impacted maxillary canines, 8% have bilateral impactions (Bishara, 1992). Canine impaction is twice more common in the maxilla than the mandible and is also twice more common in females than males. Of patients with an impacted maxillary canine, 85% are palatal and the remaining 15% are labial (Shapira and Kuftinec, 1998). Jacoby (1983) reports the number of palatally impacted maxillary canines slightly higher in his studies, ranging between 87-92%. This is in contrast to older studies that reported lower ratios of palatal to labial impactions at 2:1 (Gaulis and Joho, 1978) and 3:1 (Fournier et al 1982). At any rate, the incidence of palatal impactions is noteworthy because they very rarely erupt spontaneously without surgical intervention (Jacoby, 1983). Jacoby argues that the majority of labially positioned canines will eventually erupt spontaneously without surgical intervention, albeit in an ectopic position. He believes that a distinction should be made between "labially *unerupted* and palatally *impacted* canines."

Disruptions of normal tooth eruption are common, but their etiology is complex and normally multifactorial. There are over 100 possible local conditions, systemic conditions, and genetic disorders related to disturbances in tooth eruption (Suri et al., 2004). The etiology of maxillary canine impaction is similarly complex. According to Moyers, "the maxillary [canine] follows a more difficult and tortuous path of eruption than any other tooth" (Moyers, 1963). The permanent canine tooth bud is formed near the orbit, superior to those of the first premolar and lateral incisor (Jacoby, 1983). The inclination of its crown is also directed in a mesial and lingual position (Moyers, 1963), explaining the high rate of mesio-palatal impactions.

Moyers (1963) acknowledges that hereditary patterns are responsible for some impacted teeth, but that there are also many other possible causes. Bishara et al (1976) summarized Moyers' theories regarding impaction into primary and secondary causes:

Primary causes:

A. Rate of root resorption of deciduous teeth.

B. Trauma of the deciduous tooth bud.

C. Disturbances in tooth eruption sequence.

D. Availability of space in the arch.

E. Rotation of tooth buds.

F. Premature root closure.

G. Canine eruption into the cleft area in persons with cleft palate.

Secondary Causes:

A. Abnormal muscle pressure.

B. Febrile diseases.

C. Endocrine disturbances.

D. Vitamin D deficiency.

Others, however, argue that “the failure of permanent teeth to erupt into their normal position in the dental arches is simply due to a discrepancy between tooth size and over-all arch length” (McBride, 1979). The development of the permanent maxillary canine is completed very late relative to its neighboring teeth, making it subject to crowded conditions. Eruption will usually occur at 8-9 years of age for the permanent lateral incisor and at 10-11 years of age for the first premolar (ADA, 2012). By comparison, the permanent canine will erupt at ages 11-12. When there is an arch length discrepancy, the teeth that erupt later in series will either erupt ectopically or be impacted. Crowding in the maxillary arch will prevent the normal eruption path and the tooth “will be diverted either buccally or palatally” (McBride, 1979). Canine impaction due to crowding is less frequently observed clinically than is seen in the literature (Jacoby, 1983).

Some studies have attempted to find relationships between classes of malocclusion and tooth anomalies such as impacted canines. Basdra et al. (2000) reported that canine impaction was tripled in Class III patients while Al-Nimri and Gharaibeh (2005), reported that 45% of their patients had Class II division 2 malocclusions. The groups, however, were not large enough in either study to justify making any conclusion about the association between malocclusion type and canine impactions.

There are two other theories that have been widely supported to explain the occurrence of palatally impacted maxillary canines: guidance theory and genetic theory. Guidance theory proposes that the canine lacks guidance during eruption due to a hypoplastic or missing permanent lateral incisor (Litsas and Acar, 2011). This theory is supported by studies that show palatal impactions are frequently found in dentitions with missing or peg-shaped lateral incisors (Becker, 1995). Although lateral incisor anomalies might be genetically determined, this theory states that palatal impaction “occurs as a result of these local environmental disturbances.” Becker et al. (2002) measured the bucco-lingual and mesio-distal widths of all erupted teeth in 58 patients with impacted canines and reported that the only tooth that was statistically significant in reduction of buccal-lingual and mesio-distal width was the lateral incisor. Becker et al. (1999) also performed a split mouth study of patients with unilateral impactions using the non-impacted side as a control. He found that the side with a lateral incisor anomaly was 41.3% more likely to be affected with impaction than the non-affected contralateral side.

Genetic theory explains that maxillary canine impaction occurs because of a developmental disturbance of the dental lamina (Litsas and Acar, 2011). This theory cites evidence such as associations with hypodontia, female predilection, and increased familial and bilateral occurrence as support. Hypodontia was observed in 20% of first and second degree relatives of people with impacted canines which is 2.5 times more than the normal population (Pirinen, 1996). The prevalence of missing teeth was close to 5% which is also 2.5 times that of the normal population. Peck et al. (2002) reported a significant association of impacted canines with third molar agenesis. Unilateral impaction showed a significant correlation with maxillary lateral incisor agenesis while bilateral impaction was associated with third molar agenesis (Sacerdoti and Baccetti, 2004). These types of dental anomalies are consistent with the concept of "posterior orofacial field" (Litsas and Acar, 2011) in which there is increased susceptibility of developmental defects in the distal tooth of a series (i.e. incisors, premolars, molars). It is believed that transcription factors, such as MSX1 and PAX9, which are responsible for tooth agenesis, might also be involved in canine impaction.

Some possible sequelae of canine impaction are cyst formation, loss of arch length, and infection, but the most common is external root resorption of adjacent teeth (Shafer, 1963). The lateral incisor is particularly susceptible to root resorption because of the mesiolingal inclination of the canine during eruption (Moyers, 1963). It is important because severe root resorption can jeopardize the longevity of teeth, but it is an asymptomatic pathological process which cannot be diagnosed until a radiographic examination is performed.

2.2 Localizing Impacted Canines with Traditional Radiography

Orthodontists have historically utilized radiography for analysis of skeletal, dental, and soft tissue regions of the maxilla-mandibular complex. The earliest method of using radiographs to localize impacted maxillary canines was proposed by Clark (1910). The so called buccal object rule or what is now known as the SLOB (same lingual opposite buccal) rule involves taking two periapical radiographs of the same tooth at different angulations. The principles of geometry state that a lingual object will appear to move in the same direction as the x-ray source, but a buccal object will appear to move in the opposite direction. Armstrong et al. (2003) concluded that a correct diagnosis was made 83% of the time when using this method. The maxillary occlusal radiograph may also be used for localization of impacted canines. The radiograph is taken at an angle of 45-60 degrees to the occlusal plane and can provide information in the antero-posterior and transverse planes (Becker, 2007). Both are fairly good methods for canine localization, but are not utilized as often in orthodontics.

Cephalogram and panoramic radiographs which are more frequently used in orthodontics may also be used to localize impacted canines. The more commonly used lateral cephalogram can provide an antero-posterior position of the canine while the less commonly used postero-anterior (PA) cephalogram can provide a transverse position and angulation (Gavel and Dermaut, 1999). These two radiographs are rarely used in conjunction for purposes of localization of impacted canines due to distortion and overlap of anatomical structures.

Since its introduction in the 1950s, the panoramic radiograph has become the radiograph of choice for orthodontists when evaluating impacted teeth. The vertical position of the apex and crown are easily identifiable as is their location to adjacent teeth (Turk and

Katzenell, 1970). The determination of whether an impacted tooth is labial or palatal can be made based on its magnification on the film (Wolf, 1979). Since palatally impacted canines are farther from the film, they appear more magnified than a labially impacted canine which is closer and will appear reduced in size. When two radiologists examined only a single panoramic radiograph, a correct determination was made 89% of the time. Chaushu et al. (1999) found a similar rate of successful determination 88% of the time. Fox et al. (1995) had a lower success rate and could only make a correct determination 80% of the time.

2.3 Length of Orthodontic Treatment

Estimating the duration of orthodontic treatment is a difficult task that every orthodontist must perform well. It is important for the estimated treatment time to be accurate in order to maintain a successful orthodontic practice (Mavreas and Athanasiou, 2008). Patients reported greater satisfaction with orthodontic treatment that was completed in a timely manner (O'Connor, 2000). Satisfied patients with realistic expectations of treatment duration are also less likely to exhibit "burnout" (Brezniak and Ben-Ya'Ir, 1989). Estimates of treatment duration also influence the fee which an orthodontist will request for his services.

Many studies have evaluated treatment duration and have attempted to identify factors associated with treatment duration. Fink and Smith (1992) reported an average of 23.1 months of treatment time in 118 consecutively treated patients. Skidmore et al. (2006) reported an average of 23.5 months in 366 consecutively treated patients. Fisher et al. (2010) reported an average of 25.3 months in 400 consecutively treated patients. Beckwith et al. (1999) reported an average of 28.6 months in 140 consecutively treated patients. Vig et al. (1990) reported an average of 31.2 months in 438 consecutively treated patients. Impacted canines were listed as one of the factors for increased treatment duration in most these studies. Other relevant factors were initial malocclusion, patient compliance, and operator mechanics. Orthodontic treatment duration is influenced by many factors and is different for each individual. All patients are unique and the same can be said about orthodontists as well.

Some studies have focused exclusively on evaluating the treatment duration of patients with impacted canines. Berger and Janisse (2009) reported an average of 31.3 months of treatment in 111 consecutively treated patients with impacted maxillary canines in their practice. They reported that the duration of the 77 palatally impacted canines was on average two months longer than the 67 labial impactions. Iramaneerat et al. (1998) reported an average of 28.8 months of treatment following surgical uncovering in 50 adolescent patients with palatally impacted canines. There was an additional undisclosed period of treatment prior to the surgical uncovering. This study also attempted to correlate treatment duration to initial canine position but was unsuccessful. Stewart et al. (2001) reported an average of 28.3 months of treatment in 47 patients with palatally impacted canines. There was a statistically significant difference between this group and their control group which had an average of 22.4 months of treatment. Becker and Chaushu (2003) reported an average of 27.3 months of treatment on 10 patients with palatally impacted canines that they successfully treated. Fleming et al. (2009) reported an average of 26.3 months of treatment in 45 patients.

2.4 <u>Predicting Treatment Duration for Impacted Canines</u>

Many attempts have been made to find a correlation between the initial position of impacted canines on radiographs with treatment duration. Iramaneerat et al. (1998) investigated the initial position of palatally impacted canines on lateral cephalograms. The vertical distance from cusp tip to occlusal plane and the horizontal distance to A point-perpendicular to occlusal plane were measured. The angle formed by the long axis of the tooth relative to both planes was also measured. The authors reported that all the measurements yielded weak and insignificant correlations with treatment duration.

Stewart et al. (2001) measured the angle between the long axis of the impacted canine and the midline on panoramic radiographs. They also measured the vertical distance from cusp tip to occlusal plane and categorized it into antereroposterior sectors using an existing method created by Ericson and Kurol (1988). A statistically significant correlation was made between vertical distance of the cusp tip to the occlusal plane with treatment duration, but it too was only moderately correlated.

Zuccati et al. (2006) made a combination of measurements on both lateral cephalogram and panoramic radiographs. The panoramic radiograph was used to assess the position of the tooth in designated mesio-distal sectors. Angular measurements were also made between the long axis of the canine and: the long axes of the lateral incisor and first premolar, the midline, and occlusal plane. They used a lateral cephalogram to measure both the angle and distance between the canine and occlusal plane. A strong correlation to treatment duration was found for the distance from cusp tip to occlusal plane and for the mesio-distal sector designation.

Crescini et al. (2007) reported significant results for the angle between the long axis of the impacted canine and midline, distance between cusp tip and occlusal plane, and cusp tip mesio-distal sector designation. Fleming et al. (2009), however, found a weak correlation between the mesio-distal sector designation and treatment duration. Schubert and Baumert (2009) used a regression analysis and found significant results for all angular and linear measurements taken from a panoramic radiograph. The strongest correlation was for distance between cusp tip and its intended incisal position. The average treatment time was 25.4 months for unilateral impactions and 30.4 months for bilateral impactions.

2.5 Weaknesses of Traditional Radiography

The panoramic radiograph is certainly the most widely used image when assessing impacted canines in orthodontics. It is the most commonly used image because of its simplicity of obtaining the image, ease of viewing the image, and large field of view. The design of the machine which provides so many great benefits is also the source of its weaknesses. A two dimensional image is produced as the machine establishes a focal trough through the dental arches (Lund and Manson, 1975). Since the machine produces a two dimensional film of a three dimensional object, there is overlap of structures and distortion. Any variation in a patient's anatomy or alteration in head position will introduce error to the image. As a result, the position in which the patient's head is situated in the machine is very important (Xie et al., 1996). Magnification is also a major issue since not all the anatomical structures are equidistant to the film.

Panoramic radiographs have problems with distortion, magnification, and anatomical landmark identification. These problems are very well documented especially at the canine position where the dental arches have their greatest curvature. Even the American Board of Orthodontics acknowledges them and omits the scoring of tooth roots adjacent to the canines (ABO, 2014). The linear and angular measurements made on panoramic radiographs are affected by the weaknesses stated earlier. Studies have shown unreliability in accurately reproducing horizontal linear measurements using panoramic radiographs (Catic et al., 1998). Vertical linear measurements are slightly more reliable, but also show accuracy issues. Angular measurements show even worse reliability especially for the long axis of individual teeth in the maxillary canine region (Samawi and Burke, 1984).

2.6 Localizing Impacted Canines with CBCT

Computed tomography has traditionally been used in medicine to produce three dimensional images by capturing axial slices around objects. Recently, cone beam computed tomography is being used in dentistry at lower radiation doses than medical CT. In some cases, the newest generation CBCT images have a lower effective dose than that of a conventional panoramic radiograph (Ludlow and Walker, 2013). CBCT images are clear, three dimensional, and free of many problems that are inherent in traditional two dimensional radiographs. CBCT images are also free of magnification error so they can provide true linear and angular measurements (Haney et al., 2010). Clinicians are gradually growing more accepting of CBCT technology as radiation doses and the price of equipment are being drastically reduced.

As CBCT utilization grows, it is more widely being used in orthodontics for the visualization of impacted maxillary canines. Many studies have successfully used CBCT images to localize the position of impacted canines. The benefits of using CBCT for management of impacted teeth are: precise localization and better assessments of the dental follicle, amount of bone covering the crown, and root resorption of adjacent teeth (Walker et al., 2005). Studies comparing a set of panoramic, lateral cephalogram, and periapical radiographs to a CBCT image show that clinicians prefer the CBCT image (Botticelli et al., 2011). Clinicians showed better localization of the impacted canine using the 3D image and also more accurately detected the amount of root resorption. Canine related root resorption was found on the lateral or central incisors 45% of the time for both labial and palatal impactions (Yan et al., 2012). This rate is consistent with Ericson and Kurol's (2000) rate of 48% in a CT study.

As the use of 3D images becomes more common, there is a need for evaluation of the viability of a 3D reference system for impacted canines (Hanke et al., 2012). Hanke et al. (2012) used the palatal plane as a reference system for 3D analysis and reported reliable measurements in comparison of the impacted and non-impacted sides. The dental occlusal plane changes during the course of orthodontic treatment and is not the most ideal for evaluation of impacted canines (Katsumata et al., 2005). Katsumata et al. (2005) evaluated facial asymmetry by based on planes using skeletal landmarks. They successfully demonstrated the use of skeletal landmarks to assess facial or dental landmarks.

2.7 SureSmile™

Suresmile^{TM} (OraMetrix, Richardson, TX) is a novel orthodontic wire bending system which aids orthodontists in visualizing and treating toward a 3D treatment goal (Sachdeva, 2012; Alford et al., 2011). In 2008, the company incorporated CBCT imaging into their wire bending system (Lin and Getto, 2008). The integration of CBCT allowed the clinician to treat not only crowns, but roots of teeth as well. The company claims that SureSmile^{TM} technology reduces clinician error, decreases treatment duration, decreases number of appointments, and reduces patient discomfort (SureSmile.com, 2014).

An evaluation of nearly 10,000 completed SureSmile^{TM} patients and concluded that the median treatment time was an average of 15 months, eight months shorter than conventional treatment (Sachdeva, 2012). In addition to shorted treatment duration, patients had better scores when graded using the American Board of Orthodontic's cast/radiographic evaluation (Alford et al., 2011). No studies have investigated whether the use of CBCT imaging in conjunction with SureSmile^{TM} can decrease treatment duration for patients with impacted maxillary canines.

2.8 Summary

Impacted maxillary canines require precise localization for proper diagnosis, treatment planning, surgical exposure, and orthodontic alignment. The initial position and angulation of an impacted canine will affect the duration of orthodontic treatment. The duration of treatment is important to both the orthodontist and patient. Many studies have attempted to predict duration of treatment for impacted canines using 2D radiographs. These studies have had varying levels of success due to inherent distortion and error in panoramic radiographs. CBCT radiographs have produced images with better quality by eliminating many of the problems associated with 2D radiographs. SureSmile™ treatment shows a significant reduction in orthodontic treatment duration but it has not yet been studies in patients with impacted canines. The purpose of this study is to study how the initial three dimensional position of impacted canines relates to the duration of orthodontic treatment in patients treated with SureSmile™.

3. METHODOLOGY

3.1 Data Acquisition and De-identification

The University of Illinois at Chicago Office for the Protection of Research Subjects reviewed and determined that this study did not meet the definition of human subject research, Institutional Review Board #20130895-77207-1. To conduct the study, initial and progress CBCT images were collected for 36 patients with impacted canines who had labial fixed appliances and SureSmile™ treatment of completed cases from Dr. Edward Lin's private practice in Green Bay, Wisconsin.

For each patient, the initial CBCT and progress CBCT images were obtained after de-identification by the provider. Additionally, the following descriptive information was obtained for each patient: initial age, start date of treatment, type of surgical exposure, date of the progress CBCT scan, and date of completion of orthodontic treatment.

Patients were included if they had unilateral or bilateral impacted maxillary canines, CBCT images with necessary anatomy captured, self-ligation brackets, finished with SureSmile™, and completed treatment. Exclusion of cases occurred for four patients with impacted mandibular canines, five patients who lacked radiographic evidence of impaction, and ten patients due to limited field of view for either the initial or SureSmile™ CBCT scan. As a result, only 17 of the patients were included in this study.

The age of each patient at the start of treatment was recorded in years. Duration of alignment and duration of treatment were recorded as months. Linear distances were measured in millimeters. Angular distances were measured in degrees. Gender was not recorded or evaluated. The orthodontic brackets used by the provider for all cases were DENTSPLY GAC In-ovation R/C brackets or American Orthodontics Empower brackets with 0.018” by 0.025” slot dimension. The progress CBCT image was obtained after leveling and aligning was determined to be satisfactory by the provider. CBCT images were obtained using the i-CAT® Classic CBCT (Imaging Sciences International, Hatfield, PA) and were 0.4 mm voxels, 8.9 second, and 8x8x16 cm field of view. Statistical analysis was completed using SPSS version 20 (IBM, Chicago, IL).

3.2 Measurements

Measurements were made using Dolphin™ Imaging 3D version 11.7.05.55 beta (Patterson Dental System, Chatsworth, CA). Linear and angular measurements were recorded using Dolphin Imaging.

Each CBCT image was first oriented so that three planes could be constructed using the method developed by Katsumata et al. (2005) in Figure 1. The sagittal plane was constructed through sella, nasion, and basion. The axial plane was constructed through sella and nasion, perpendicular to the sagittal plane. The coronal plane was constructed through basion, perpendicular to the sagittal and axial planes.

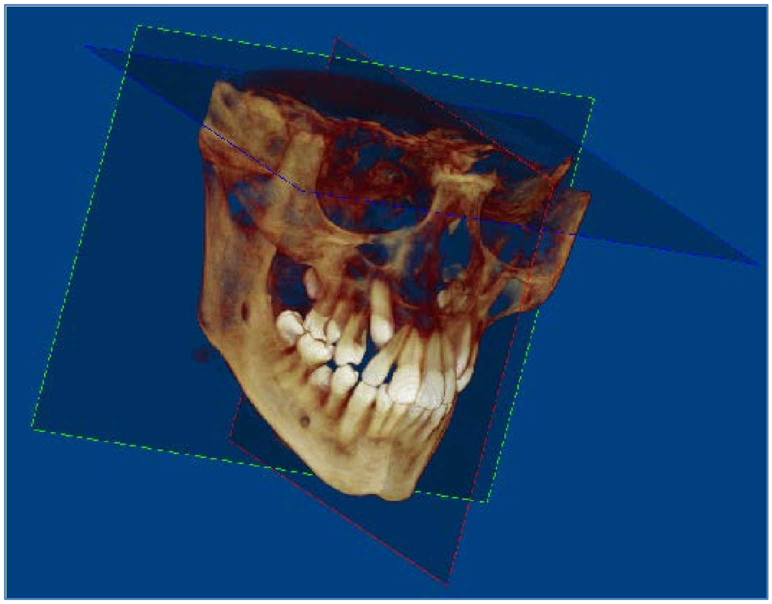

Figure 1. Example of oriented CBCT image. Constructed sagittal, axial, and coronal planes.

On the initial CBCT image, the impacted canine's cusp tip and apex were digitized. Linear measurements were recorded relative to each of the three planes (Figures 2a,2b). Two angular measurements were made, one in the frontal view and one in the lateral view (Figures 3a,3b). In the frontal view, the angle between the long axis of the impacted canine and the sagittal plane was recorded. In the lateral view, the angle between the long axis of the impacted canine and the coronal plane was recorded. On each progress CBCT image, the same measurements were made as was done on the initial CBCT, except for the angular measurements.

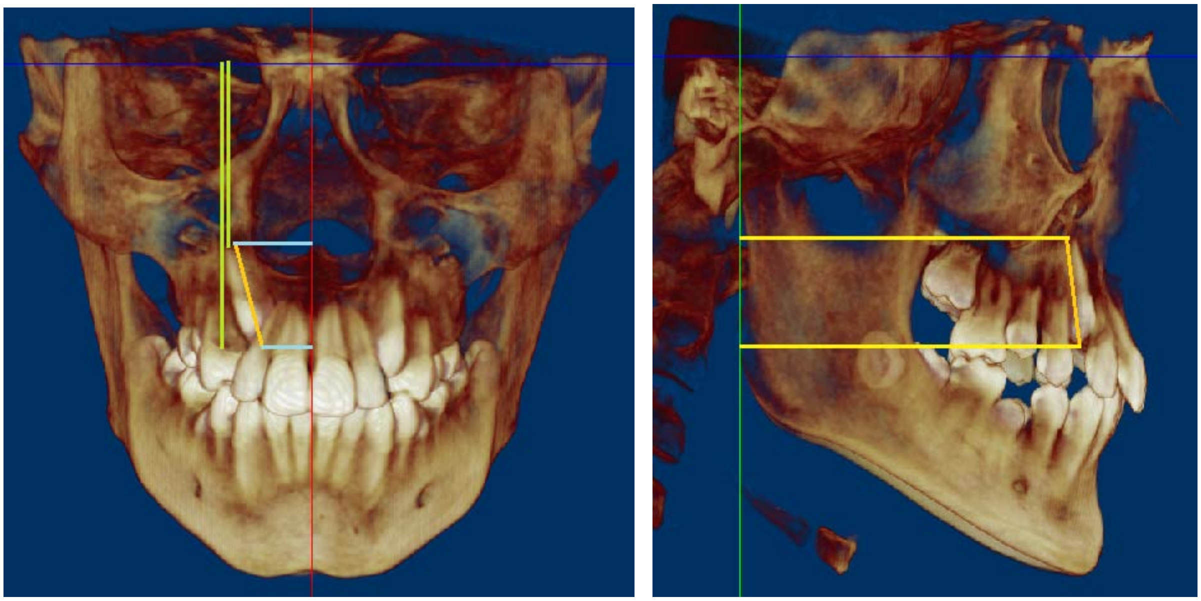

Figure 2. Example of linear measurements. 2a (left). Long axis of canine drawn in gold, with blue lines depicting sagittal plane measurements and green lines depicting axial plane measurements. 2b (right). Yellow lines depicting coronal plane measurements.

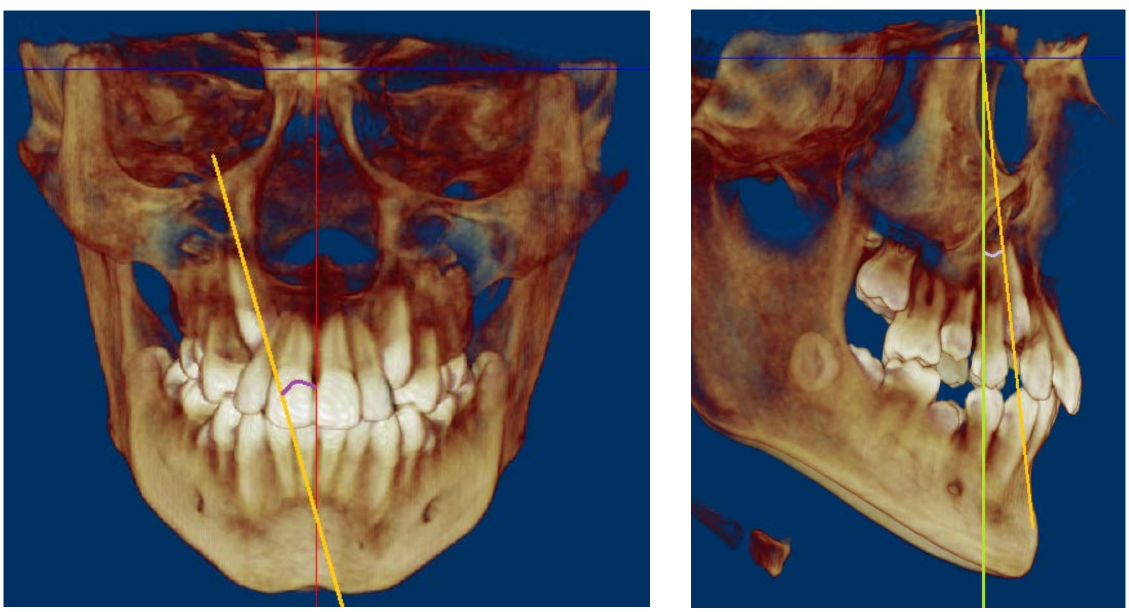

Figure 3. Example of angular measurements. 3a (left). Angle measured in the frontal view between long axis of canine and sagittal plane. 3b (right). Angle measured in the lateral view between long axis of canine and coronal plane.

The three dimensional Euclidean distance was calculated between the initial and progress scans for the apex and cusp tip using the following equation:

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + (p_3 - q_3)^2}.$$

This equation provides the distance that the apex and cusp tip of each impacted canine moved from its initial (*p*) to aligned (*q*) position.

The durations of alignment and total treatment were calculated using a web based duration calculator (http://www.timeanddate.com/date/duration.html). The treatment duration for each control group was obtained from published results.

3.4 **Statistical Analysis**

The distribution of the treatment duration was not distributed normally so a non-parametric test using Spearman's rank correlation coefficient was used. Linear measurements, angular measurements, and Euclidean distance between initial and progress scans were each tested for correlation with treatment duration.

A one-sample t-test was used to test the relationship between the impacted canine treatment group to the ten control groups.

4. RESULTS

4.1 Results

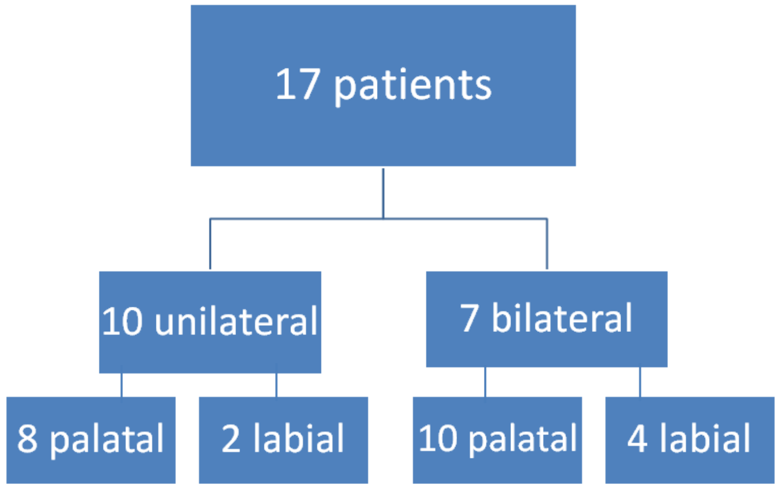

Figure 4. Breakdown of patients in this study.

There were 17 patients included in this study. 10 patients had unilateral canine impaction and 7 had bilateral impactions. There were 18 palatal impactions and 6 labial impactions.

TABLE I
MEAN PATIENT AGES

Mean	Youngest	Oldest
13.54 years	**11.77 years**	**16.40 years**

The mean patient age was 13.54 years old. According to the ADA (2012), the maxillary canine is normally erupted between 11-12 years old. Those patients under this age range, however, showed radiographic evidence of impaction of the maxillary canine.

TABLE II
LATERAL INCISOR ROOT RESORPTION

None	Mild	Moderate	Severe	Missing Tooth
19	3	0	1	1

Lateral incisor root resorption was assessed in categories of none, mild, moderate, severe, or not applicable for missing incisors. 19 of 24 lateral incisors displayed none, while 3 displayed mild and only 1 displayed severe root resorption. One patient had a congenitally missing lateral incisor.

Six linear measurements were made on the initial CBCT image and compared to the duration of treatment. Of these six, the initial vertical position of the apex (Y_i apex) was the only one to show a statistically significant correlation ($p<.05$, $r=.502$). The Euclidean distance of the apex and cusp tip between initial and progress scans showed no significance to treatment duration.

TABLE III
MEAN LINEAR MEASUREMENTS FOR THE APEX

X_i Apex	Y_i Apex	Z_i Apex	X_f Apex	Y_f Apex	Z_f Apex	Total Distance
12.8 mm	38.6 mm	70.2 mm	13.0 mm	49.2 mm	72.3 mm	11.9 mm

TABLE IV
MEAN LINEAR MEASUREMENTS FOR THE CUSP TIP

X_i Cusp	Y_i Cusp	Z_i Cusp	X_f Cusp	Y_f Cusp	Z_f Cusp	Total Distance
10.8 mm	57.1 mm	72.4 mm	17.4 mm	70.6 mm	74.2 mm	16.6 mm

Angular measurements were made in the frontal and lateral views on the initial CBCT image and compared to the duration of treatment. The frontal view angle showed a statistically significant correlation ($p<.05$, $r=.449$) to the duration of alignment. The frontal view angle also showed statistically significant correlation ($p<.05$, $r=.435$) to the duration of total treatment.

TABLE V
MEAN ANGULAR MEASUREMENTS

Frontal View	Lateral View
18.3º	9.7º

The mean duration of alignment for the impacted canines was 11.3 months. The mean duration of total treatment was 20.0 months. The longest total treatment was 45.2 months for a bilateral impaction patient and the shortest was 11.5 month for a patient with a unilateral palatal impaction. The treatment group in this study was compared to 10 control groups from other studies. The duration of treatment for the treatment group was statistically significant in comparison to all but two of the control groups.

TABLE VI
MEAN TREATMENT DURATION

Alignment Duration	Total Treatment Duration	High	Low
11.3 months	20.0 months	45.2	11.5

The treatment group in this study showed a statistically significant reduction in treatment duration when compared to three of the five non-impaction controls. It also showed a statistically significant reduction in treatment duration when compared to all five impaction control groups.

TABLE VII
COMPARISON TO NON-IMPACTION CONTROL GROUPS

	Fink & Smith	Skidmore et al.	Fisher et al.	Beckwith et al.	Vig et al.
Duration	23.1 mo.	23.5 mo.	25.3 mo.	28.6 mo.	31.2 mo.
N	118	366	400	140	438
p value	NS	NS	<.05	<.001	<.001

TABLE VIII
COMPARISON TO IMPACTION CONTROL GROUPS

	Fleming et al.	Becker et al.	Stewart et al.	Iramaneerat et al.	Berger et al.
Duration	26.3 mo.	27.3 mo.	28.3 mo.	28.8 mo.	31.3 mo.
N	45	10	47	50	111
p value	.006	.002	<.001	<.001	<.001

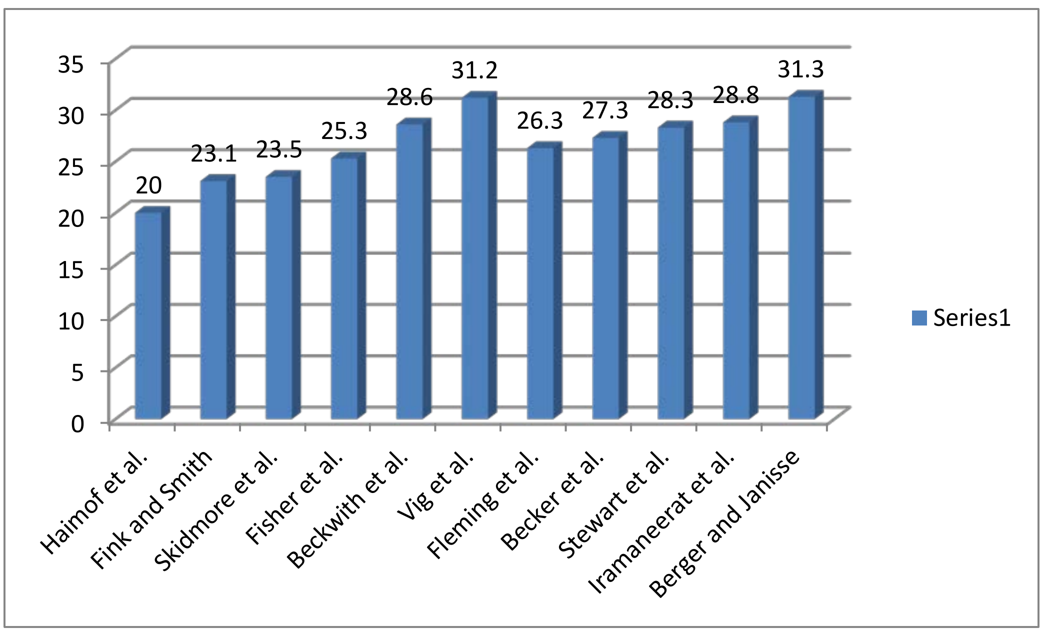

Figure 5. Graph showing treatment duration of treatment group and control groups.

5. DISCUSSION

5.1 Discussion

The utilization of a three-dimensional CBCT image in this study for evaluation of impacted canines proved to be very useful in this study. It provided accurate localization of the tooth, adjacent teeth, and anatomical landmarks. As stated earlier, the weaknesses of two-dimensional radiographs are well documented in the literature. The use of CBCT images is now the gold standard because it provides clear 3D images which allow for accurate reproducibility of linear and angular measurements for research purposes without as much error.

The results of this study are in partial agreement with published literature regarding impacted maxillary canines. Out of the sample of 24 impacted teeth, 18 were palatal impactions and 6 were labial impactions. This 3:1 ratio is similar to one published study (Fournier et al., 1982), but slightly lower than most others (Jacoby, 1983; Shapira and Kuftinec, 1998). The occurrence of bilateral impactions in this study was 41% and is over five times that found in the literature (Bishara, 1992).The small sample size in this study might be the reason for this large discrepancy.

Overall, there was a very low rate of root resorption on the lateral incisor in this study when compared to the literature (Yan et al., 2012). This is a major benefit of utilizing CBCT for assessment of root resorption because it provides a more accurate estimation than traditional 2D radiographs. The clinician demonstrated a more aggressive nature in exposing the impacted tooth and beginning alignment of the impacted tooth at an earlier age. This could be viewed positively because the younger ages could have contributed to better compliance

Descriptive statistics for the linear differences in apex (Table III) and cusp tip (Table IV) position show that the apex of impacted canines was on average moved only 0.2 mm from initial to final with respect to the sagittal plane. The cusp tip moved 6.6 mm on average with respect to the sagittal plane. This is indicative of a desirable tooth movement called controlled tipping, in which the crown moves in one direction with minimal movement of the root occurring. The vertical components of both the apex and cusp tip showed the most change from initial to final with differences of 10.6 mm and 13.5 mm, respectively. Differences in measurements in the antero-posterior direction were also minimal with the apex moving 2.1 mm and the cusp tip moving 1.8 mm.

The use of CBCT imaging provided mixed results in drawing meaningful conclusions from the relationship of linear or angular measurements and treatment duration. The only statistically significant linear measurement was the initial vertical position of the impacted canine's apex ($p<.05$). It showed a moderate correlation ($r=.502$) to the duration of treatment. This result confirms findings by Iramaneerat et al. (1998), Stewart et al. (2001), and Zuccati et al. (2006) who also found correlations between vertical position of the tooth and treatment duration. All other linear measurements showed no statistical significance in relation to treatment duration. This current study appears to offer no new information in predicting treatment duration based on linear measurements since vertical measurements made on panoramic radiographs have been shown to usually be reliable (Xie at al., 1996).

Table V shows the descriptive angular statistics for both the frontal and lateral views. In the frontal view, the average angle between the long axis of the impacted canine and the sagittal plane was 18.3°. In the lateral view, the average angle between the long axis of the tooth and the coronal plane was 9.7°. Angular measurements of the frontal view were statistically significant to duration of alignment ($p<.05$) and total treatment ($p<.05$). There was a moderate correlation found with the duration of alignment ($r=.449$) and the duration of total treatment ($r=.435$). The significance of the frontal view angular measurements is consistent with other studies (Stewart et al., 2001; Crescini et al., 2007).

Orthodontic treatment in general has many confounding variables which cannot always be accounted for but may affect treatment duration (Skidmore et al., 2006; Beckwith et al., 1999). Even with one provider, there may be many different methods to align an impacted canine and treat the malocclusion. Certain patient factors may also play a role in treatment duration. The patient's biologically determined rate of tooth movement is a factor in how quickly the tooth can be aligned. Other factors may also be related to compliance and appliance breakage.

The treating orthodontist whose cases were used in this study used a soft tissue laser to expose almost all of the impacted canines. He is able to uncover the tooth and bond a button or bracket in his own office, essentially bypassing an outside referral to a surgeon or periodontist. By doing so, he is able to place a bonded button in the most ideal position for him and immediately apply orthodontic traction. This more than likely has some effect on the short treatment durations that he was able to achieve. Orthodontists will often wait and allow unerupted teeth to spontaneously erupt. This, however, may take months or may not occur altogether. By using the soft tissue laser, our provider was more aggressive in pursuing impacted teeth earlier and applying orthodontic traction much earlier in treatment. Referring a patient to an outside surgeon can prolong treatment due to a variety of reasons. Many times, patients do not follow up with surgical referrals immediately due to finances, lack of availability of the patient and referring doctor, or due to fear of a surgical procedure.

This study has many strengths compared to past studies investigating the treatment success of impacted maxillary canines. In this study, skeletal landmarks were utilized to assess the position of the impacted canine. Skeletal landmarks, especially those of the cranial base used in this study, are much more reliable when comparing initial and final measurements. In the past, the occlusal plane was used as a reference plane, but studies have shown that the occlusal plane changes throughout treatment and retention. In addition, this study measured the initial and actual aligned position of the impacted canine. In other studies, the aligned position was only estimated which could have introduced error in the measurements. Lastly, this is the first study to investigate the outcome of patients with impacted canines treated with SureSmile™.

5.2 Limitations

The most apparent limitation of this study was the small sample size of patients. This is difficult when performing any study on impacted canines due to the low prevalence found in the population which makes it difficult to find a sufficient number of patients. It was also challenging to find cases that had a full field of view pretreatment and progress CBCT image with the necessary anatomy captured in each image. This study had an additional limiting factor because all of the patients were treated with SureSmile™. Using CBCT to design this wire bending technology has only been in existence since 2008 which limits the number of completed impacted canine cases which are available for analysis. This study is the first to evaluate the treatment duration of patients with impacted maxillary canines treated with CBCT and SureSmile™. Since CBCT technology is becoming more widely used, future studies could benefit from a larger quantity of available records.

Since the sample was limited in its size, the grouping of palatal and labial impactions was necessary to have an adequate sample in order to provide meaningful results. Statistical analysis could not be performed with two separate but smaller groups. The same also applied for unilateral and bilateral canine impactions subjects. A smaller sample of patients also made it difficult to distinguish between different malocclusion types and severities.

Current 3D orthodontic software is still rudimentary in its analysis of CBCT images. Dolphin 3D version 11.7.05.55 is still in beta version meaning that it still has flaws and bugs which need user feedback to be improved. As user adoption increases, more measurement tools and analyses will surely become available.

5.3 Further Research

As the effective dose and cost of CBCT is constantly reduced with each newer generation of equipment, its use will continue to grow and allow for larger patient samples. As more SureSmile™ cases are completed every day, future research could investigate a larger sample of patients with impacted canines. This will allow researchers to classify subjects into many more specific treatment groups (e.g. unilateral vs. bilateral, labial vs. palatal). Classifying patients into different malocclusion types will also help improve results.

Future studies could also compare groups of patients treated with SureSmile™ among many clinicians to determine if the reduction in treatment length could be attributed to it. Other groups could also include patients treated with SureSmile™, but referred out to a surgeon for exposure.

6. CONCLUSION

The results of this study have shown that the initial vertical position of impacted canines has a significant effect on treatment duration. All other linear measurements showed no significance in relation to treatment duration. The frontal view angle of the long axis of the tooth to the sagittal plane also shows a significant effect on treatment duration. The treatment group in this study had a significantly shorter duration of treatment when compared to controls.

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