INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

University of Alberta

Palatally Impacted Maxillary Canines:
Factors Relating to Duration of Treatment

by

Dr. Jeffrey A. Stewart ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Orthodontics

Department of Dentistry
Edmonton, Alberta
Spring 2000

National Library of Canada

Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services

Acquisitions et services bibliographiques

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-60180-3

Canada

University of Alberta

Library Release Form

Name of Author: Jeffrey A. Stewart

Title of Thesis: Palatally Impacted Maxillary Canines: Factors Relating to Duration of Treatment

Degree: Master of Science

Year this Degree Granted: 2000

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as hereinbefore provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Jeffrey A. Stewart
556 Carriage Ct.
Kelowna, B.C.
V1W 3B3

Date: Jan 22/00

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Palatally Impacted Maxillary Canines: Factors Relating to Duration of Treatment by Jeffrey A. Stewart, in partial fulfillment of the requirements for the degree of Master of Science in Orthodontics.

Paul W Major, Supervisor

Kenneth E. Glover

Philip C. Williamson

Giseon Heo

Date: Jan 28/00

Abstract

The first objective of this study was to determine the relation that the initial position of a palatally impacted maxillary canine, as seen on a panoramic radiograph, had on the duration of orthodontic treatment. A second objective was to determine whether a difference in treatment duration existed between bilateral and unilateral palatally impacted canine cases.

A total of forty-seven adolescent subjects were chosen, twenty-nine unilateral cases and eighteen bilateral cases. All subjects had full fixed orthodontic appliances placed. The treatment duration of this group was compared to a control group with similar characteristics but without the impacted canine.

The results showed that the average duration of treatment for the control group was 22.4 months, for the unilateral impacted group 25.8 months, while the bilateral impacted canine group had a treatment duration of 32.3 months. The length of treatment for the impacted canine sample was related to the age of the patient at the start of treatment with the younger patients requiring a longer treatment duration. The younger the patient the more severely impacted the canine was found to be. The bilateral impacted canine group had at least one canine more severely impacted than the impacted canine in the unilateral impacted group. At a distance from the occlusal plane of less than 14.0 mm, treatment duration averaged 23.8 months, but if the canine was impacted at greater than 14.0 mm from the occlusal plane, treatment duration averaged 31.1 months.

Life is too short no matter how long you live, so live.

Anonymous

Dedication

This thesis and all of the work which went into it is dedicated to my wife, Tara, and our two beautiful children, Alyssa and Halle, who left our comfortable life in Kelowna for a two year adventure in Edmonton. Their encouragement and support was frequently needed and much appreciated.

To my parents, who gave me encouragement, advice, support and hard work which helped me to become what I am today and will be tomorrow.

Acknowledgements

To Ken Glover, who gave me the opportunity.

To all of the graduate orthodontic instructors, especially Dr. Z. M. Pawliuk, for the knowledge and time they provided.

To the orthodontic staff, Brigette, Gail, Susan, Wendy, Pat, Adelpha and Cindy for all their help and support.

To Drs. Carlyle, Puszczak and Major and their wonderful staff for their help in collecting the data used in this study.

To all my fellow residents, especially Bob and Kirby , who made the learning easier and the program far more enjoyable.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

List of Tables

List of Tables (cont)

List of Figures

Chapter One

Introduction

And

Literature Review

1.1 - Introduction

The achievement of a normal occlusion is the result of so many interrelated variables that the occasional existence of this ideal would seem to defy the law of probability. Hereditary and developmental, muscular, osseous and dental, systemic and local, physical and emotional, and other factors and combination of factors contributing to the establishment of the occlusion must operate within precise limits. The multiplicity and complexity of these factors are such that the wonder is not that malocclusion exists, but that occasionally there can be found a mouth with no orthodontic problem.

Arthur S. Ash[1]

In most individuals the permanent teeth will erupt into their proper positions and replace their primary predecessors. However, sometimes a permanent tooth is prevented from erupting into the dental arch at its normal time. For this paper the definition of an *impacted tooth* is "a tooth whose eruption is considerably delayed and for which there is clinical or radiographic evidence that further eruption may not take place".[2] Impacted teeth are a frequently encountered clinical problem among patients being treated in a typical orthodontic practice. Considerable interest is attached to the presence of impacted teeth in an orthodontic patient, not only on account of the pathologic conditions they may produce, but also because of their impact on the diagnosis and treatment planning process required for each individual patient.

The type of treatment prescribed for an impacted tooth depends on the particular tooth impacted; the field of specialty of the practitioner first involved, whether a general dentist, periodontist, orthodontist or oral surgeon; and the level of that practitioners' experience with this problem. Such treatment may be as simple as observation and monitoring, or more complex, including surgical extraction, surgical exposure with or without orthodontic traction (via a variety of methods) or auto-transplantation.

Maxillary canines are one of the most commonly encountered impacted teeth and often present a quandary for the clinical orthodontist. They are considered to be an important tooth esthetically and functionally but impacted maxillary canine cases are perceived to be more difficult and time consuming than the average orthodontic case, requiring more clinical time and a higher fee. Does one try to bring the impacted canine into the arch, commonly assuming that this procedure will add much time and additional patient expense to an average treatment, or does one extract the involved tooth (or teeth), thus saving time and money for the patient, but perhaps at the expense of acceptable esthetics and long term function? How much time will be added and how much extra expense should be charged to the patient?

A determination of the extra treatment time required for a palatally impacted canine, based entirely on subjective clinical experience, is the most often used method in setting the treatment fee and the estimated length of time the patient is told they will be in orthodontic appliances. Often this estimated treatment time is incorrect, with treatment being no more difficult and taking no longer than for an average orthodontic case, or conversely, resulting in the patient wearing their orthodontic appliances far longer than they were initially told and becoming frustrated with their treatment. Additionally, the efficiency of the orthodontic office may be affected if treatment ends up taking far longer and requires many more office visits than the orthodontist first estimated. The examination of factors which may have an influence on the duration of orthodontic treatment when a palatally impacted canine is involved would be beneficial to both orthodontists and orthodontic patients. It may allow the orthodontist to more accurately answer two of the first questions asked by patients and their parents: "How long will I need to wear my braces?" and "How much is all this going to cost?"

1.2 - Statement of the Problem

In spite of its importance to both orthodontists and patients, very few studies have attempted to evaluate factors which may influence the duration of orthodontic treatment. Fewer studies have evaluated the factors that may affect the duration of orthodontic treatment in cases involving impacted maxillary canines. No studies were found that examined whether the position of the palatally impacted canine, as seen on a panoramic radiograph, or whether the presence of a unilateral or bilateral palatal canine impaction, have an influence on this treatment duration. The investigation of how, or even if, these variables influence the length of time patients will be required to wear orthodontic appliances may be beneficial to clinical orthodontists in more accurately determining office time and cost required in treating these often complex orthodontic problems. A better estimate of treatment duration would also benefit patients in giving them a better idea of their time and cost commitment.

1.3 - Purpose

The first purpose of this retrospective research study is to examine whether the initial horizontal position, vertical position and angulation of a palatally impacted maxillary canine have any influence on the duration of orthodontic treatment in an adolescent sample. The second purpose is to determine whether the presence of bilateral palatally impacted canines will have an effect on treatment duration when compared to unilateral impactions. This will be accomplished by the examination of panoramic radiographs, which are most commonly used by orthodontists to assess the severity of maxillary canine impactions and in making treatment decisions involving these teeth.

Additionally, a pilot study will be done to investigate the reliability of the most commonly used horizontal and vertical reference lines used to quantify the position of the impacted maxillary canine on the panoramic radiograph, as used in recent papers on impacted maxillary canines.

1.4 - Research Questions

1. Is there a difference in duration of orthodontic treatment between an adolescent control sample with no impacted maxillary canine, and an adolescent sample with the presence of at least one palatally impacted maxillary canine?

2. Does the horizontal position, vertical position, and angulation of a palatally impacted canine, as seen on a panoramic radiograph, show a relation to treatment duration?

3. Does the presence of bilateral, as compared to unilateral, palatal canine impactions have a relation to treatment duration?

4a. Is the occlusal plane a reliable horizontal reference line in determining the vertical position of a palatally impacted canine?

4b. Is a line bisecting the long axes of the maxillary central incisors a reliable vertical reference line in determining the angulation of a palatally impacted canine ?

1.5 - Null Hypotheses

1. There is no significant difference in treatment duration between an adolescent sample without an impacted maxillary canine, and a sample with at least one palatally impacted maxillary canine.

2. There is not a significant relationship between the horizontal position, vertical position and angulation of the palatally impacted maxillary canine, as seen on panoramic radiographs, and treatment duration.

3. There is not a significant difference in treatment duration between a bilateral palatally impacted canine case and a unilateral palatally impacted canine case.

4. The most common horizontal and vertical reference lines, as cited in current literature on impacted canines, are not reliable reference lines.

   a. The occlusal plane is not a reliable horizontal reference line for determining the vertical position of a palatally impacted canine.

   b. A vertical line bisecting the long axes of the maxillary central is not a reliable vertical reference line for determining the angulation of a palatally impacted canine.

1.6 - Literature Review

1.6.1 - Theories of Tooth Eruption

Tooth eruption is defined as the movement of a tooth from its site of development within the alveolar process to its proper position in the oral cavity.[3] The mechanism of this eruption is an enigma which has been a matter of long historical investigation, but even today has not been definitively answered.

A variety of theories of eruption have been proposed, but to be considered valid a theory must include the following factual observations in tooth eruption[4]:

1. teeth move in three dimensions as they erupt;
2. teeth erupt with varying characteristic, stage-specific speeds; and
3. teeth arrive at a functional position that is inheritable.

Early theories explained tooth eruption by root elongation or the proliferation of Hertwig's root sheath [3-5] yet it has been shown that rootless teeth, or even metal or silicone replicas, will still erupt.[6,7] However, root elongation may have an influence on the eruption speed of teeth.[4] Other theories which have been studied as causes of tooth eruption include pulpal pressure, pulpal growth, vascular pressure, and traction from fibroblasts.[4]

Recent reviews of eruption[4,8,9] have concluded that eruption is a multifactorial process and that the dental follicle has a pivotal role. Alveolar bone remodelling superior and inferior to the tooth bud, formation and maturation of the periodontal ligament, the presence of blood vessels surrounding the developing tooth, and the presence of various biochemical events all seem to be necessary, at varying stages, for the eruption of teeth through the alveolar process and into occlusion.

1.6.2 - Incidence of Impacted Teeth

Patients rarely go to their dentist with a chief complaint of an impacted tooth and, since there is often no pain or swelling, they are commonly unaware that this abnormality is present. Generally, it is the family dentist who first observes the presence of a retained primary tooth and then radiographically discovers an impacted permanent tooth. Impacted permanent teeth are a relatively common anomaly among patients seen in a typical orthodontic practice. Mead[10] reported on 1462 full mouth radiographs of "white people" who were patients at his office, with no ages mentioned, and found an incidence of 18.9% having at least one impacted tooth, of which 1.6% were impacted maxillary canines.

Montelius[11] compared Chinese and Caucasian peoples, no ages given, for the incidence of impacted teeth and found the rate of overall tooth impaction to be much higher in Chinese people (31.1%) than in Caucasians (12.2%). Interestingly, though not divided into maxillary and mandibular canines, the rate of canine impaction was far lower for the Chinese (1.7%) than the Caucasian people (5.7%).

In a comprehensive study of 3784 routine full-mouth radiographs, Dachi and Howell[12] found an overall impaction rate of 16.7%, with 0.92% being maxillary canines. Radiographs from 3599 patients who were 20 years and older formed the basis of the study of third molars. An additional 244 sets of radiographs from patients between the ages of 13 and 20 were included in the study of impacted canines and other teeth. All radiographs were from the Indiana University School of Dentistry and the Dental School of the University of Oregon.

Kramer and Williams[13] studied 3745 panorex radiographs from oral surgery patients at the Harlem Hospital, a mainly Negro population, and reported an 18.2% overall incidence of impaction, with 1.2% being maxillary canines. No age ranges were mentioned in the study.

Using a sample of 7886 patients who visited the Faculty of Dentistry at The University of British Columbia, Shah, Boyd and Vakil[14] found that 546 individuals (6.9%) presented with 918 impacted teeth. Just 0.68% of the total patient sample showed maxillary canine impactions with 7 cases of bilateral impactions and 47 unilateral cases for a total of 61 impacted maxillary canines. Radiographs of individuals seven years and over were analysed to determine the presence of impacted canines.

Grover and Lorton[15] evaluated 5000 panoramic radiographs of U.S. Army recruits, with an age range of 17 to 26 years, and found an incidence of 2.84% impacted maxillary canines. For an overall rate they used a category of unerupted/impacted teeth, and found that 96.5% of the 5000 persons had radiographic evidence of one or more unerupted/impacted teeth.

The tooth most frequently impacted was the third molar, followed by the canine, and the second and first premolars.[10,12-15] The published data showed that the prevalence rate of maxillary canine impaction ranged from approximately 1.0% to 3.0% [10,12-15,24]. Most of the above studies did not separate the location of the impactions into labial and palatal.

The establishment of the incidence between palatal and labial impactions is a difficult problem. Palatally impacted canines very rarely erupt spontaneously and are usually detected after the age of 12-13 years, the approximate normal time of eruption for these teeth. Labially unerupted canines are usually seen before this age and are often surgically exposed at that time, in conjunction with the start of orthodontic treatment. It is impossible to say that some of these labially displaced teeth would not eventually erupt on their own, albeit in an ectopic location. For this reason, Jacoby[16] recommended that labially displaced teeth be referred to as *unerupted* or *blocked out* and palatally displaced teeth as *impacted*.

Considering the above problem with the establishment of the incidence of labial displacement versus palatal impaction, it is no surprise that the reported incidence varied widely in different studies. In one of the earliest radiographic studies of impacted maxillary canines, Röhrer[17] radiographed 64 patients with 73 displaced maxillary canine teeth and reported a ratio of 3.6:1 palatal to labial.

Hitchin[18] found a rate of 6.6 palatally displaced canines to every 1 labially displaced. Nordenram and Strömberg[19] investigated 374 patients with 500 impacted maxillary canines, age range from 9 to 68 years, and reported a ratio of 1.5:1 palatal:labial.

Thilander and Jakobsson[2], in a widely cited paper, studied 192 boys and 192 girls, mean age 11.5 years, and followed all those with unerupted canines for 7 years. Depending at the age the children were examined, the palatal to labial position ratio varied from approximately 1:6 at the first examination to approximately 2:1 by the last examination. Of the 7 canines which were palatally displaced and unerupted at the first examination, 5 were still palatally displaced and unerupted at the last examination 7 years later (mean age 18.5 years). The two that erupted were originally classified as "slightly palatally situated". Conversely, of the 41 unerupted canines originally classified as labially displaced at the first examination, only 3 remained unerupted 7 years later. In their adult sample, the ratio was 3:1 palatal:labial.

In a paper presented before the Canadian Association of Orthodontists in 1969, Johnston[20] stated that in his experience "the palatally impacted canines occur almost 50 times as often as labially impacted canines." No data was presented.

Fournier et al[21] reported on 38 teeth treated in their clinic and found a palatal to labial ratio of 3:1. Jacoby in 1979[22] found a ratio of 12:1 palatal:labial, and in 1983[16], with a different patient sample, he reported a ratio of 6.6:1.

Wolf and Mattila[23] radiographed 100 young adults in whom an impacted maxillary canine had been observed on a previous radiographic examination, and found the ratio to be approximately 9:1 palatal:labial.

In another widely cited paper on impacted canines, Ericson and Kurol[24] studied 84 children, ages 10-15 years, with ectopic eruption of 125 maxillary canines. They also found a ratio of palatal to labial displacement of approximately 3:1.

If the subjective statement by Johnston[20] is disregarded, the ratio of palatal impaction to labial displacement of maxillary canines varied between approximately 2:1 to 9:1. [16-24]

1.6.3 - Maxillary Canine Development

The permanent maxillary canine begins calcification at approximately 6-12 months of age, only a few months after the beginning of calcification of the permanent first molars and central incisors, but takes nearly 6 more years to achieve complete eruption.[25] It begins formation between the roots of the first deciduous molars, superior to the crypt of the permanent first bicuspid[26], very high in the anterior wall of the maxillary sinus, under the floor of the orbit[27]. Because of the pyramidal shape of the maxilla, the permanent canine is found palatal to the root of the deciduous canine.[18]

Dewel[28] found that the crown of the upper canine normally varied only a few degrees from vertical but will retain an abnormal inclination once assumed. He felt that this was due to the location of the apex of the root, the length of the root, its time of eruption, and the contours of the crown; these four factors resist any change from that inclination once fully erupted.[28] On the subject of the upper canine, Dewel[29] stated that "Of all teeth it has the longest period of development, the deepest area of development, and the most devious course to travel from its point of origin to full occlusion."

At about 3 years of age, the developing maxillary canine is below the orbit, above the floor of the nose, and between the nasal cavity and the maxillary sinus.[27] By 6 years of age the crown of the canine is at the level of the nasal floor, positioned lingual to the apex of the deciduous canine, and directed mesially.[27] It follows a mesial path of eruption until it reaches the distal aspect of the root of the lateral incisor, and then is guided by the lateral incisor to a more upright position until it is fully in occlusion.

The final position of the canine is largely dependent upon the presence, the proper position and alignment of the lateral incisor. If there is a malposition or malalignment of the lateral incisor, the canine may lose the proper guidance from this tooth and continue to move forward, possibly until it reaches the central incisor root.[27] It may then erupt in a transposed position with the lateral incisor. If the lateral incisor is congenitally missing, the canine may again continue to move medially until it comes in contact with the central incisor and then be guided into the oral cavity, in a more mesial position than normal.[27]

Ericson and Kurol[30] radiographically followed the position of maxillary canines in 41 children aged 8-12 years in whom a clinical investigation had indicated a disturbance in eruption. They found that a difference in palpation of the maxillary canines on the two sides (asymmetry) was a strong indication of aberrant eruption in children 10 years and older, but was not indicative before this age. Early radiographic examination, before the age of 10 years, does not always indicate the final path of eruption. The initial larger investigation on this topic by the same authors[31] suggested that if the canine is palpable on the labial it will erupt, usually in a favourable position. If neither maxillary canine can be palpated in the normal positions and the rest of the occlusal development is advanced, an abnormal path of eruption should be suspected and followed up radiographically. Their last recommendation was that if the lateral incisor is late in eruption or shows a pronounced labial displacement or proclination, it should always be radiographically investigated as this position may indicate a labial ectopic eruption of the canine. This must be differentiated from normal distal tipping of the lateral incisor during these ages, which has been referred to as the "ugly duckling" stage of development.[25]

Coulter and Richardson[32] used annual lateral and "depressed postero-anterior" (head tilted down 30°) cephalometric radiographs of 30 subjects aged 5-15 years to follow the eruption of the maxillary canines. They found that the canine showed significant annual movement in a posterior direction between 7 and 12 years of age (11.48 mm total); in the vertical plane, maxillary canines showed annual movement between 5 and 12 years of age, always toward the oral cavity (18.56 mm total); and in the lateral plane, these canines showed small palatal movement between 5 and 9 years of age, and then buccal movement thereafter. The total lateral movement ended up being only 2.67 mm between the ages of 5 and 15 years. There was however, because of the initial palatal movement and then buccal movement, an average difference of 5 mm between the most palatal and most buccal positions of the canine crown tip. Using Pythagoras' theorem, these authors have quantified the total movement of maxillary canines, from ages 5-15 years, to be about 22 mm - long and tortuous maxillary canine eruption is indeed!

In a study published in 1998[33], a "transverse retrospective" investigation using panoramic radiographs of 305 children between the ages of 4 and 12 years who had no orthodontic treatment, it was concluded that the upper canine increases its inclination mesially, until a maximum angle of 98° (to a straight line through both suborbitary points, with a range of 85° - 120°) is reached at the age of 9 years, at which point the tooth progressively uprights until it emerges into the oral cavity at approximately 91°.

However, the individual variability of the degree of this inclination at the various ages was considerable and could not be used to predict any abnormal path of eruption. Although common at earlier stages of development, when the development of the lateral incisor was complete, the canine was found to overlap it radiographically in only 7%-11% of the cases. According to these authors, this may be a sign of an eruptive disorder and they suggested preventive measures be taken to avoid permanent canine impaction. Namely, they recommended the extraction of the deciduous canine.

1.6.4 - Sequelae of Impaction

Shafer et al[34] noted the following possible sequelae which can be related to maxillary canine impaction:

1) labial or lingual malpositioning of the impacted tooth;

2) migration of the neighbouring teeth and resultant loss of arch length;

3) internal resorption of the impacted tooth;

4) dentigerous cyst formation;

5) external root resorption of the impacted or neighbouring teeth;

6) infections, especially from partially erupted teeth;

7) referred pain; and

8) any combination of the above.

In addition, Becker[35] mentioned the possibility of resorption of the enamel of teeth that are unerupted over many years. This possible consequence happens mainly in adults and is rare in younger people. However, it is also possible that an impacted canine may cause no deleterious effects during the lifetime of the person.

The most common, and irreversible, harmful effect of impacted canines seems to be root resorption of the adjacent lateral and/or central incisors.[24,26,36-44] According to Masseler and Malone[45], root resorption was found in approximately 86% of 13,263 permanent teeth examined, and there was no patient who did not have a tooth without root resorption. They concluded that resorption potential varies from person to person, but is not an uncommon finding. Up to 12.5% of ectopically erupting canines caused resorption of the adjacent incisors but this may have been even higher due to the limitations inherent in evaluating resorption with standard intra-oral radiographs.[24]

Linge and Linge[36,41] investigated upper anterior root resorption with standardized intraoral radiographs and found that the 22 cases with an impacted maxillary canine (not distinguished between labial and palatal) showed an average resorption of 2.2 mm on the adjacent lateral incisors. They postulated that this may be due to the increased intrusive force on the lateral incisor as the canine is being extruded orthodontically or may be due to the increased duration of orthodontic treatment when an impacted canine is involved. They also found that the corrected canine very rarely showed any root resorption.

Ericson and Kurol[38-40] found that the incisors will be resorbed mainly with palatally impacted canines and is less common with labial impactions. They found that it may be difficult to diagnose resorption with conventional intra-oral radiographic methods, especially if the canine is overlapping the adjacent incisor. In these cases they recommended the use of polytomography[38] or computed tomography (CT).[40] With these two methods they could better localize the resorption lesion and found lesions that were not discernible with the conventional radiographs. Most of the resorptions were found in the middle third of the incisor roots and not the expected apical area. The midroot location, together with the fact that lingual and buccal resorptions account for approximately 50% of the lesions, may explain why so many of these resorptions escaped detection with routine periapical radiographs. Resorption of the incisor roots due to ectopic eruption of the canine was most common in the 11-12 year age group, but may occur as early as 9-10 years. The predisposing factors for resorption were stated to be[39]:

1) resorption was three times more common in girls than boys;

2) resorption cases showed a more advanced dental development;

3) the canine was more medial in the dental arch; ie. it was always positioned medially to the midline of the adjacent incisor;

4) the canine showed a slightly more horizontal path of eruption.

Others[42] speculated that the normal-sized and early developing lateral incisor root obstructs the deviated path of impacted canines and have a considerably greater chance of being damaged by resorption than a small or peg-shaped lateral incisor, which may have a shorter[46] and later developing root[47] than the normal lateral incisor.

Another potentially harmful sequelae to canine impaction is the formation of a dentigerous cyst. Sain et al[48] reported on a case where an impacted canine was displaced superiorly to the floor of the orbit due to a large dentigerous cyst.

Other consequences of impacted maxillary canines mentioned in the literature, summarized by Hitchin[18], include pain, headaches and insomnia, all of which were subsequently 'cured' upon the removal of an impacted canine.

1.6.5 - Etiology of Maxillary Canine Palatal Impaction

In general, the causes for late or slow eruption of teeth may be either generalized or localized.[49] Generalized or secondary causes include abnormal muscle pressures, febrile diseases, endocrine disturbances, and vitamin D deficiency.[49] The most common causes for either labial or palatal maxillary canine displacement are usually localized and any one or a combination of the following factors have been put forth as possibilities, as summarized by Bishara[50]:

1) tooth size-arch length discrepancies;

2) prolonged retention or early loss of the deciduous canine;

3) abnormal position of the tooth bud;

4) the presence of an alveolar cleft;

5) ankylosis;

6) cystic or neoplastic formation;

7) dilaceration of the root;

8) iatrogenic;

9) trauma; and

10) idiopathic, including primary failure of eruption.

More recently, specific to palatal impaction of the maxillary canine, the congenital absence of the maxillary lateral incisor, variation in its root size, and variation in the timing of its root formation[51], or a dental anomaly of genetic origin[52] have also been suggested as causative factors.

Dewel[28] found that palatally impacted canines occur most often in cases which otherwise present with normal arch form and occlusion of the teeth, with enough space to accommodate them in the arch. He found it odd that such an indispensable tooth, as indicated by the fact that it is almost never congenitally missing and having such a long powerful root, would be displaced so often.

Lappin[26] suggested that the presence of a supernumerary tooth could be a cause of canine impaction but occurs so rarely in the area of the maxillary canine that this is not a significant etiologic factor. He felt that a more important cause may be the position of the canine tooth bud and the long and devious way it has to go to erupt into occlusion. If for some reason the resorptive factors do not attack the deciduous canine root, this could lead to the impaction of the permanent canine. Lappin was one of the first to suggest a genetic component to palatal impaction, as shown by the occurrence of other family members having an impacted canine. Lappin also agreed that crowding of the maxillary dental arch is not a factor in palatal impaction of the maxillary canine.

Fastlicht[53] mentioned the presence of supernumerary teeth, leaning habits, dentigerous cysts, prolonged retention of deciduous canines with septic root canals, or the premature extraction of deciduous canines and molars as causative factors. In contrast to Lappin[26] and Dewel[28], Fastlicht thought that "the deficient mastication in our times with the resultant lack of development of the maxilla undoubtedly" is a factor in maxillary canine impaction, but he also noticed that many impactions occur in well-developed arches. He wrote that the etiology is not yet clear and that some unknown cause exerts an influence on the displacement of the dental follicle and mentioned that heredity plays a very important role.

Hitchin's[18] investigation into the impacted maxillary canine mentioned etiological factors that included a more labial than normal position of the permanent lateral incisor, thus deflecting the canine palatally; inadequate development of the maxilla, especially in those cases associated with a cleft palate; the early loss of the deciduous canine, but more often the delayed resorption of the root of the deciduous canine; and supernumerary teeth were found to be the main factor in 7 out of 109 maxillary canine impactions he studied.

Thilander and Jakobsson[2] did the first longitudinal study on impacted canines, following 384 adolescents for 7 years, starting with a mean age of 11.5 years. By the end of the study there were only 5 palatally impacted canines which failed to erupt. The position of the tooth was found to be the most important factor for non-eruption - if the tooth was palatal to the lateral incisor, it tended to stay there and not erupt into the oral cavity. The lack of resorption of the deciduous canine was found by these authors to be a result rather than a cause of impaction of the permanent canine. They found no convincing evidence that an enlarged follicular sac was the cause of impaction. Severe crowding generally resulted in a labial displacement of the canine.

Takahama and Aiyama[54] performed a cephalometric radiographic study of 408 parents of patients with clefts and 2959 parents of non-cleft patients, and concluded from their results of a significantly higher incidence of upper canine impaction in the cleft group fathers, that maxillary canine impaction may be a possible microform of cleft lip and palate.

The purpose of Jacoby's work[16] was to establish the relationship between arch length and canine impaction by separating the labial impactions from the palatal impactions. In this study, 85% of the 40 palatally displaced canines had sufficient or excess space in the arch to erupt. Two of the palatal canines (5%) were thought to be related to agenesis of the ipsilateral lateral incisor, while four (10%) were thought to be related to peg-shaped lateral incisors. Two of the palatal canines in which there was not sufficient space in the arch occurred in the same patient who the author felt had a general hypodevelopment of the skeletal tissues and had some hidden symptoms of cleft palate. Of the remaining four palatally impacted canines without sufficient space in the arch, two of the patients had the opposite maxillary canine labially displaced, while one other had a crossbite on the side with the palatally impacted canine. In contrast, only one of the labially displaced canines showed sufficient space in the arch for the canines. Jacoby felt that it is evident that arch-length deficiency is the major etiologic factor in labially displaced canines. In contrast, he stated that excessive space in the maxillary canine area could allow the canine to move palatally in the bone and find a place behind the buds of the other teeth and eventually become palatally impacted. Jacoby suggested that labially displaced canines be referred to as *unerupted* while the term *impacted* be used only for palatally displaced canines.

Sain et al[48] described a case of a maxillary canine which was impacted and displaced through the maxillary sinus and superiorly to the floor of the orbit by a dentigerous cyst. The patient initially came in with a chief complaint of the delayed eruption of a permanent maxillary central incisor, and only after a radiographic examination was the impacted canine seen. After resolving the cyst the impacted canine was brought into occlusion.

Brin, Solomon and Zilberman[55] presented two cases of trauma to the anterior area of the mouth that eventually resulted in an impacted canine on the affected side. In one case the trauma resulted in shortening of the root of the lateral incisor which these authors felt affected the path of eruption of the adjacent canine tooth. In the other case presented, the trauma produced a misalignment of the anterior segment which caused the lateral incisor to lose "the desirable relationship with the adjacent canine bud at a critical stage of dental development." They recommended that special attention should be paid not only to the teeth directly injured by the trauma, but also to the development of apparently unharmed neighbouring teeth.

McConnell and colleagues[56] investigated whether patients with impacted canines have a transverse maxillary deficiency and whether other factors, such as arch length, arch perimeter or arch form contributed to the incidence of impacted maxillary canines. They did not separate labial and palatal impactions for their results but did show a 2.5:1 ratio of palatal to labial impactions. They found that patients with canine impactions do have a transverse maxillary deficiency in the anterior part of the dental arch compared to a control group, but arch form, arch perimeter, arch length and intermolar width did not significantly contribute to the incidence or location of canine impaction.

Today, the two major theories regarding the most common cause of palatal impactions of maxillary canines are the 'guidance theory' and the 'anomaly of genetic origin'. The guidance theory suggests that a proper size and timely formation of the adjacent lateral incisor root is required to guide the erupting canine to its proper location in the arch. Should this root be smaller than average or late in formation then the canine has a greater chance of becoming displaced palatally. The anomaly of genetic origin theory suggests that palatal displacement is a positional anomaly of the canine follicle, occurs with other dental anomalies and is very often familial.

In their study of 7886 British Columbian individuals, Shah et al[57] found an incidence of congenitally missing teeth of 3.56%, including third molars. Of these missing teeth, approximately 13% were maxillary lateral incisors, for an approximate total of 0.5% incidence of congenitally missing lateral incisors in this population. When third molars were excluded, the incidence of missing teeth drops to only 1.82%. They also found an incidence of 0.32% for the occurrence of peg teeth. These authors quoted other studies, on different populations, which showed an incidence of between 0.5% and 8.4% for peg-shaped lateral incisors.

Miller[58] noted that the congenital absence of the adjacent permanent lateral incisor has an influence on the eruption of the canine. He felt that the smaller root of the retained deciduous lateral incisor allows the canine to pass medially over its apex and then become palatally impacted.

Becker, along with various colleagues, has done much research on the incidence of anomalous maxillary lateral incisors in relation to palatally displaced canines. In an early publication, Becker at al[51] obtained 55 cases of palatally displaced canines from

633 consecutive patients from an orthodontic practice and an additional 33 cases fulfilling the same criteria from the orthodontic department of a dental school and another private practice. They classified the lateral incisors adjacent to the palatally impacted canine as absent, peg-shaped, small (mesio-distal width equal to or smaller than its mandibular counterpart), or normal. Their results showed that females were affected with a palatally displaced canine 2.5 times more than males, and in 45% of all cases the impaction was bilateral. These researchers found that in almost half the cases (48%) the adjacent lateral incisor was either absent or of an anomalous size. They believed that small or peg-shaped lateral incisors tend to develop later than normal and are insufficiently developed to provide critical guidance in the very early stages of development and migration of the canine. Absent lateral incisors are obviously also unable to provide this needed guidance. They found that their 5.5% rate of congenitally absent lateral incisors in their palatal canine population was much higher than that seen in the general population (2.1% in a Jewish population that they quoted, 0.5% in a Canadian population[57]). Becker et al[51] suggested that there appear to be two processes in the palatal displacement of the maxillary canine. The first is a developmental one where the absence of guidance by the congenitally missing, late-developing, or small-rooted adjacent lateral incisor allows the erupting canine to move towards the palatal side. The second one related to a later period, when the canine is moving down into the narrower part of the alveolus and then is prevented from its normal labial movement by the roots of the permanent lateral incisor.

An evaluation of 70 palatally displaced canines and 106 controls done by

Becker and others[46] found the average length of lateral incisors adjacent to a palatally displaced canine to be 2.12 mm shorter than those adjacent to normally erupted canines, with 1.4 mm of this discrepancy attributable to a shorter root. The length of the central incisors was not found to be significantly different in the two groups. They concluded that there is a definite link between small lateral incisor crown size and the incidence of palatal displacement of the adjacent canine; there is a link between a short lateral incisor root and the incidence of palatal displacement of the adjacent canine; and there is a definite link between lateral incisor crown size and root size. They thought that the shorter root, together with the lateness of development of anomalous teeth, deprive the canine of needed guidance in the early stages of development.

Brin, Becker and Shalhav[59] examined a random sample of 2440 adolescents (1173 males and 1267 females) and found a rate of 7.1% of missing or anomalous lateral incisors (as classified in their earlier study above), and a rate of 1.53% for palatally impacted canines. There was no statistical difference between females and males for either palatally displaced canines or absent or anomalous lateral incisors. They found that almost 43% of the palatal canines were associated with anomalous or missing lateral incisors. They calculated that there is a 0.98% probability of a palatal canine adjacent to a normal lateral incisor, an 11.5% chance of a palatal canine adjacent to a peg-shaped lateral incisor, 9.8% when a small lateral incisor is present and 5% when the lateral incisor is congenitally absent. These authors reported that 72.6% of the palatal canines were found in an Angle Class I malocclusion, 20.5% in a Class II malocclusion, and only 6.8% were found in a Class III malocclusion.

Since these anomalies of lateral incisor development are known to be under strong genetic control, Zilberman, Cohen and Becker[60] investigated whether first degree relatives of patients with palatal canines would exhibit an increased prevalence of the anomalies. Of the parents of these patients examined, 5.1% were found to have palatal canines with 30.8% having absent or anomalous lateral incisors. Of the siblings examined, 11.4% were found to have palatally displaced canines and 28% showing a developmental problem with lateral incisors. These findings in the parents and siblings are considerably higher than in the general population studied previously by these researchers (1.5% palatal canines, 7.1% anomalous or missing lateral incisors).

Others have also studied whether there was a relation between a palatal canine and an adjacent small or peg-shaped lateral incisor. Using a Scottish population, Mossey et al[61] undertook a retrospective study of 182 subjects from records of orthodontic patients with palatally displaced canines. Eighty percent of the subjects had a unilateral impaction and twenty percent had bilateral impactions. All twenty-three of the peg-shaped lateral incisors were associated with a palatally impacted canine, and there were twice as many small laterals on the affected side. Twenty-three subjects had thirty-three congenitally absent lateral incisors, with only nineteen of the absent laterals related to a palatally displaced canine. In contrast to the findings of Becker et al[46], Mossey's group found no association between a smaller lateral incisor crown size and a shorter root length. This group found that 56% of the subjects had a Class I malocclusion, 29% a Class II division 2 malocclusion, 9% a Class II division 1, and only 6% a Class III malocclusion.

Oliver and colleagues[62] studied a Caucasian group of 31 subjects and an Oriental group of 29 subjects, both from a dental school population, who showed the presence of unilateral maxillary canine impaction. They found that crowding in the Oriental population was significantly greater than in the Caucasian sample, and that most of the canine impactions in the Oriental population were to the buccal while most of the Caucasian impactions, which had less crowding, were to the palatal. They concluded that a lateral incisor adjacent to an impacted canine is slightly, though statistically insignificantly, narrower and shorter than the contralateral incisor, but this should be considered with care due to the small sample size.

In the other major alternative theory regarding palatal impaction of the maxillary canine, Peck, Peck and Kataja[52] argued that this malocclusion is a positional variation which develops due to genetic factors and not due to local factors such as retained deciduous canines, anomalous lateral incisors or dental crowding. Peck et al[52], in a review of the literature, grouped their evidence into five categories:

1) Occurrence of other dental anomalies concomitant with PDC (palatally displaced canines)

It is known that a genetic etiology exists for at least three of the abnormalities associated with PDC: tooth agenesis, generalized tooth size reduction, and systematic lateness of tooth development. Peck et al[52] mentioned that another positional anomaly of the maxillary canine, transposition with the first premolar, also occurs with a high frequency in combination with the above specific anomalies and, like them, it also appears to be of genetic origin. They suggested that the evidence clearly points to the idea that PDC is not an isolated phenomena but that it frequently occurs in association with other genetically interrelated dental anomalies.

2) Bilateral occurrence of PDC

Peck et al[52] listed ten other studies which reported bilateral occurrences of PDC, ranging from 17% to 45% of the total number of cases in each study. They stated that this rate is far beyond chance occurrence and points to an intrinsic etiology such as a genetic mechanism. This rate appears to be similar to rates of bilateralism of other dental anomalies under genetic control, such as maxillary lateral incisor agenesis, with a rate of 29% to 46% of cases, and maxillary canine-first premolar transposition with a bilateral occurrence of 23% to 43% of cases studied.

3) Sex differences in PDC occurrence

Sex ratios are useful in identifying biological phenomena with genetic links involving the sex chromosomes. The male-female ratios of PDC occurrence ranged from M1:F1.3 to M1:F3.2 in the ten studies listed in their paper[52], which compare favourably with sex ratios recorded for other dental anomalies of genetic origin, such as hypodontia (M1:F1.3 to M1:F1.6) and maxillary canine-first premolar transposition (M1:F3.8).

4) Familial occurrence of PDC

Results of family studies[52] have shown evidence of increased rates of occurrence of PDC among other family members. Two of the studies suggested a genetic transmission for the PDC anomaly with only the study by Zilberman, Cohen and Becker[60] not subscribing to this theory. They supported the theory of a genetic anomaly of the lateral incisors resulting in a lack of guidance for the canine, which mechanically results in a palatal impaction.

5) Population differences in PDC occurrence

Peck et al[52] reported that a dichotomy exists in PDC prevalence between Europeans and those of African or Asian ancestry. Most of the cases reported in the literature for PDC are from those with a European background and reports of PDC are rare in African and Asian dentitions. They calculated the prevalence rate ratio for the occurrence of PDC in Europeans to Asians to be European 5: Asian 1. They suggested that these racial differences of PDC occurrence support the genetic involvement in the etiology of this anomaly, similar to other orofacial anomalies with a racial predilection, such as cleft lip/palate and maxillary canine-first premolar transposition.

Peck, Peck and Kataja[52] suggested that early theories of palatally displaced canines such as retained deciduous canines or inadequate arch length are no longer viable in light of more recent research. They also suggested that the presence of an anomalous lateral incisor or a congenitally absent incisor along with the palatally displaced canine suggests nothing about causality, but that they are simply "coincident traits appearing within the context of a larger, biological mechanism of control, namely, genetics." However, they stated that the basis of genetics for this anomaly does not rule out the occasional influence of environmental factors such as early dentofacial trauma in the genesis of some palatal impactions.

Soon after the above publication, Dr. Adrian Becker[63] wrote a letter to the editor of 'The Angle Orthodontist' disputing the conclusions of Peck et al[52], which was then replied to by Peck, Peck and Kataja[63]. These two letters quoted much of the same research on palatally impacted canines to defend their individual theories but arrived at different conclusions as to the cause. Whichever view turns out to be correct it appears that genetics is involved, either involving only the lateral incisors and subsequent lack of mechanical guidance for the canine, or having a larger role and being responsible for the abnormal position of the canine, the anomalous size or absence of the lateral incisors, and other anomalies which may occur with a palatally impacted canine.

1.6.6 - Diagnosis and Localization of Impaction

The diagnosis and localization of canine impaction is based on clinical, digital and radiographic examinations. Bishara[50], in one of his reviews on maxillary canine impactions, listed the following clinical signs which may be indicative of canine impaction: (1) delayed eruption of the permanent canine or prolonged retention of the deciduous canine beyond 14 to 15 years of age; (2) absence of a normal labial canine bulge; either inability to locate the canine position through intraoral palpation of the alveolar process or the presence of an asymmetry in the canine bulge noted during alveolar palpation; (3) presence of a palatal bulge; (4) delayed eruption, distal tipping, or splaying of the lateral incisor.

Most authors agreed that maxillary canines have usually erupted into full occlusion by approximately 12 years of age[18,25,28,53]. After this age the absence of a canine in the arch, without a history of extraction, usually suggests that it is impacted. Very rarely is a maxillary canine congenitally absent. According to Ericson and Kurol[31] the absence of the 'canine bulge' before the age of 10 years, in most cases, is not indicative of any eruption problems with the canine. Because of individual variation in tooth development and eruption, general somatic maturity and dental development are considered more important than age when assessing the need for a radiographic assessment. In their evaluation of 505 school children, aged 8-12 years, they found that at 10 years of age 29% of the children had non-palpable canines, only 5% at 11 years of age, and only 3% at later ages. They recommended the following indications for radiographs: 1) asymmetry on palpation or a pronounced difference in eruption of canines on the left and right sides; 2) the canines cannot be palpated in the normal positions and the occlusal development is advanced; 3) the lateral incisor is late in eruption or shows a pronounced buccal displacement or proclination.

Others[27,65,66] suggested that the inclination of the lateral incisor may give a clue to the position of the unerupted canine. A distal inclination of the lateral incisor (ugly duckling stage) indicated a close relationship of the canine crown to the incisor apex. If the lateral incisor crown has a labial tilt then the crown of the canine will often be found on the labial aspect of its root. Palatal displacement of the canine usually does not affect the position of the lateral incisor but in some cases the latter tooth will be retroclined, possibly in crossbite. Mobility of the lateral incisor suggests resorption of its root, often due to malposition of the canine.

In summary, where it is not possible to palpate the canine by about ten years of age, and an ectopic path of eruption is suspected, then radiographic assessment is necessary to localize the canine.

Röhrer[17] gave a very early, detailed description of taking and reading radiographs to localize the position of displaced and impacted teeth. Hitchin[18], before the invention of the panoramic radiograph, recommended lateral intraoral films at different angulations, occlusal films, and/or lateral and postero-anterior cephalometric films to localize the impacted tooth.

Most contemporary papers[67-69] recommended the use of two intraoral periapicals at different angles (parallax method, Clark's method, tube-shift method, buccal object rule) to easily determine whether a tooth is buccal or lingual to another tooth, and/or using occlusal films along with a panoramic radiograph to locate the spatial position of the impacted tooth.

A few publications have investigated using only a panoramic radiograph to localize an impacted maxillary canine. Wolf and Mattila[23] took a series of panoramic radiographs on 100 young adults with 116 impacted canine teeth. More than 80% of the teeth in a horizontal or mesio-angular position, in relation to the occlusal plane, were situated on the palatal side with less than 20% located labially or in the middle of the alveolus. In contrast, of the teeth in a vertical position, only one was situated on the palatal aspect of the arch. All 45 cases in which the canine crown was projected at the site of the root of the central incisor were located palatally. Of the canines located at the site of the lateral incisor about 75% were palatally positioned. Of the fifteen canines located in the proper position mesio-distally, only 13% were palatally displaced, with 60% centrally located and the rest labially displaced.

When trying to determine the labio-palatal position of the impacted canine from panoramic radiographs on the basis of magnification, knowing that a palatally impacted tooth will be magnified more and appear larger than one in the line of the arch or labially displaced, a dental radiologist made a correct assessment in 88% of the cases while another radiologist correctly assessed 89% of the cases. The greatest accuracy was achieved with regard to palatally located teeth, which were correctly identified in 95%-99% of the cases. However, these authors[23] concluded that the determination of the labio-palatal location of impacted teeth based on a single panoramic radiograph was unreliable and the method was not suitable for clinical use.

Another investigation[70] used only panoramic radiographs from100 patients to localize impacted maxillary canines. These authors concluded that correct prediction of palatal unerupted maxillary canines using differential magnification on panoramic radiographs was possible in about 80% of the cases. They also recommended that further radiographs are required to localize the position of the impacted canine with more certainty.

A recent study[143] had the objective to develop a reliable method of diagnosing the position of a displaced canine on the basis of a single panoramic radiograph. They used a ratio of the width of the impacted canine to the width of the homolateral central incisor and found that the panoramic radiograph can serve as a useful indicator for determining the position of an unerupted maxillary canine in some instances. However, in many cases other radiographs were still necessary.

Jacobs has published prodigiously on the subject of localizing impacted canines.[71-75] He suggested that there are three accurate radiographic methods of localization: (1) the parallax method; (2) the use of two radiographs taken at right angles to each other; (3) stereoscopy. The parallax method (tube shift, Clark's rule, buccal object rule) is the most widely used technique and can be done via a horizontal tube shift or a vertical tube shift.

1.6.7 - Prevention/Interception of Maxillary Canine Impaction

It would seem to be a wise course of action to prevent or intercept the impaction of the maxillary canine and prevent the detrimental sequelae which can occur due to this anomaly. Broadbent, in a communication to Lappin[26], demonstrated by taking a series of anteroposterior and lateral headfilms of children, starting at the age of 6 years, and at intervals of 3-6 months, that it is possible to observe with great accuracy the path of eruption of the permanent canine. By noting deviations from normal, Broadbent could predict an abnormal eruption path of the permanent canine and would then remove the deciduous canine so that the permanent canine could then assume its normal position and not become palatally impacted. This would be an effective solution to prevent canine impaction but it is no longer ethical to take radiographs every 3-6 months on children to monitor the remote possibility of an impaction occurring.

Williams[68] recommended the dental age of 8 years to be the best time to begin observation of the intra-bony eruption of the canine for detection of possible complications. In Class I uncrowded malocclusions where maxillary canine bulges are absent, he recommended radiographs to ascertain the position of the permanent canines. If the canine appeared to have a mesial tilt and a position lingual to the incisor teeth, Williams suggested the removal of the deciduous canine. The extraction of the deciduous canine can also be helpful at later ages, but he said that the final improvement in the permanent canine position may not be as successful as that seen at the earlier ages.

Recommendations by Ngan et al[76] included observation of the intrabony movement of the maxillary canine between the ages of 8 and 10 years, and early extraction of the primary canines to help redirect the path of eruption of the permanent canines if a problem is suspected.

In a frequently cited paper on the prevention and interception of maxillary canine impaction, Ericson and Kurol[77] followed 46 ectopic maxillary canines in 35 individuals, ages 10 - 13 years, in the first prospective longitudinal study on the prevention of palatal impaction. All cases showed no or minimal space problems. In all of the cases the primary canine was extracted, with the result that 78% of the permanent canines showed a change to a normal eruption from the previously palatal position, most within 6 months and all within 12 months. None of the other cases normalized after 12 months. Their results showed that, in this age group, 91% of the canines normalized when the permanent canine crown was distal to the midline of the lateral incisor. Conversely, the success rate fell to 64% when the permanent canine crown was mesial to the midline of the lateral incisor. In contrast to earlier publications, Ericson and Kurol[77] recommended that before the age of 10 years, spontaneous correction of potentially displaced maxillary canines may occur and extraction of the deciduous canine is normally not indicated, unless the patient shows very early dental maturity. Extraction of the deciduous canine is the treatment of choice in the age group 10 - 13 years when the permanent canine has a palatal ectopic eruption path.

Jacobs[78] published two case reports which followed the guidelines of Ericson and Kurol[77] which were both successful in intercepting a potential palatal impaction of maxillary canines. Jacobs[79] also published two case reports which were outside the guidelines of Ericson and Kurol[77] but which were also successful in correcting the path of eruption of palatally displaced canines. This latter study suggested that extracting the primary canine and allowing 12 months of observation to see if the permanent canine does correct its path of eruption may be worth trying in most palatally impacted canine cases.

In a more recent prospective study[80], 39 consecutive patients with 47 palatally displaced canines, age range 9.3 - 14.5 years, were followed for two years after the extraction of the deciduous canine. Two patients aged 9.3 years showed early dental development and the 14.5 year old showed late dental development. Overall 62% of the canines achieved a normal eruptive position, 19% showed some improvement and a further 19% failed to improve or their position deteriorated. Of the 17 permanent canines which were mesial to the midpoint of the adjacent lateral incisor, only 5 successfully erupted into position (29% success compared to Ericson and Kurol's 64% success[77]). Of the 22 canines that overlapped the adjacent lateral incisor root by half or less, 16 (73%) were successfully normalized. When no overlap was present there was a 100% success rate. A reported trend was that the chance of a successful return of the canine to a normal eruptive pathway decreased if the original canine angulation exceeded 31 degrees. However, the angulation effect exerted less influence on the chance of success than the degree of overlap of the adjacent incisor root. Vertical height and eruptive distance were not found to be significant factors.

1.6.8 - Treatment Alternatives

Once a palatally impacted maxillary canine has been diagnosed and localized, and any preventive/interceptive measures have failed in normalizing the position of the tooth, some type of active treatment is indicated. There are many proposed treatment alternatives for the correction of the palatally impacted canine in the literature. Consideration needs to be given to the attitude of the patient, the space present at the canine site and in the arches generally, the general state of the dentition, mobility and/or resorption of adjacent teeth, the position of the canine, the presence of a dilaceration of the root of the impacted canine, the age and health of the patient, and surgical difficulties and/or contraindications to surgery. Some of the more common methods of treating a patient with a palatally displaced maxillary canine, as summarized by Bishara[50], include:

1) No treatment.

2) Extraction of the impacted canine and movement of the first premolar into its position.

3) Extraction of the impacted canine and prosthetic replacement of the canine.

4) Extraction of the canine and a segmental osteotomy to move the buccal segment mesially to close the space.

5) Surgical exposure, allowing natural eruption to occur.

6) Autotransplantation of the impacted canine.

7) Surgical exposure of the canine with orthodontic treatment to bring the

canine into proper occlusion.

The patient may not wish to consider treatment of the impacted canine if they feel that their appearance is satisfactory with the deciduous canine in place. In these cases the patients need to be warned of the possible sequelae of leaving the impacted tooth in the alveolus, and of the need for periodic radiographic monitoring of the retained impacted permanent canine.

The patient may opt for the removal of the impacted canine, to prevent some of the possible problems from occurring, but leaving the deciduous canine in place. They must be advised that the prognosis for the deciduous canine lasting for their lifetime is slim, and that some prosthetic dental treatment or orthodontic treatment will probably be needed in the future.

One non-invasive technique to bring palatally displaced canines into the arch was stated to have a 66% success rate with proper case selection.[81] The technique consisted of continuous light pressure on the soft tissues overlying the impacted canine, effected by the use of a removable appliance with an expansion screw angulated in the direction in which the canine must move to align itself in the arch. The author stated that the normal eruptive forces seemed to be stimulated to cause the tooth to erupt into occlusion. Age did not seem to be a prohibitive factor, but it was suggested that the 11 to 16 year age group holds the most chance of success.

Allowing free physiologic eruption of an impacted tooth, before orthodontic appliances are placed, was recommended by some authors.[26,82,83] The oral surgeon exposes the palatally impacted canine and removes all of the surrounding soft tissue and as much of the surrounding bony crypt as is practical, without exposing the cemento-enamel junction of the impacted tooth or damaging the roots of adjacent teeth. The surgeon then either places a surgical pack to prevent tissue overgrowth of the exposed tooth[17,83] or cements a plastic crown form over the canine.[82] A channel can also be placed in the bone towards the deciduous canine to aid in the movement of the permanent canine in this direction[82]. The proponents of this method stated that most of the teeth treated with this method erupted sufficiently within 6-12 months to proceed with full orthodontic therapy, a savings of 6-12 months of time in orthodontic appliances, expense and inconvenience to the patient.

In those rare cases where dental crowding is part of the diagnosis in a palatally impacted canine case, or if extractions are required for improved facial esthetics, consideration must be given to extracting the impacted permanent canine and the deciduous canine and replacing the space with the adjacent first premolar. Many orthodontists traditionally attempt to bring the impacted canine into position because of their feelings on the importance of the canine to function and esthetics. However, because this procedure is not guaranteed, it is advised that any extraction of a premolar be delayed until the prognosis of bringing the canine into position is more certain. Nonetheless, in some cases the extraction of the canine is the better idea due to its position of impaction where attempting to bring it into occlusion could damage adjacent tooth roots, presence of ankylosis, if it is undergoing external or internal root resorption, age of the patient, or excellent alignment of the existing premolar in the canine position. In some cases this premolar substitution can be quite acceptable, with little compromise in either esthetics or function. Perhaps due to the pervasive thought among orthodontists on the importance of the canines, there is little literature on the substitution of premolars for canines.[84,85]

Occasionally, the extraction of the impacted canine with prosthetic replacement will be the best choice of treatment for the patient. This may be due to a perceived social stigma to wearing orthodontic appliances as an adult, or limited problems in other areas of the mouth requiring a relatively short duration of orthodontic treatment, and the extra time required to close the space or bring the canine into the arch is not desired by the patient. As long as the patient understands the limitations of prosthetics, potential future replacements required, and potential problems of prosthetics, this is a viable option to replacing an impacted canine. Autotransplantation is a little used technique in North America to place an impacted tooth into its proper position but does have a good success rate when cases are carefully selected.[86-89] A very similar technique, called 'repositioning' or 'surgical alignment' [90,91], is when the impacted tooth is surgically moved into the arch but is not removed from the tissues during treatment. Instead, it is rotated about its apex into the proper position.

The most common method of bringing palatally impacted canines into occlusion is via surgical exposure, affixing some kind of attachment to the canine, and orthodontically pulling the tooth into the arch. There are many ways which have been used to place an attachment on the impacted canine to provide the force to bring it into the line of occlusion. These include cementing a pin into a hole drilled in the incisal edge of the canine[92,93], fabricating a cast onlay or band with a loop to cement over the exposed canine[20,53,94], cementing a celluloid crown form with a piece of band metal inserted into a slot in the crown form to which traction can be exerted[95], tying a ligature wire around the canine crown[67,96,97], cementing a preformed orthodontic band[98], embedding a wire loop into a prepared cavity in the crown of the impacted tooth and filling the cavity with restorative material[99], and cementing a button on to the dry impacted canine with Durelon.[100] Today, the most common method of fixing an attachment to an impacted canine is to etch the dry tooth with acid and bond a button, eyelet or orthodontic bracket directly to the tooth, either at the time of surgery or soon thereafter.

However the attachment is made to the tooth, a force must then be applied to bring the impacted canine into position. Some [21,101-103] recommended the use of a removable appliance and elastics to apply the force, reasoning that it is more economic and provides better control of the force direction than full banding.

Vardimon et al[104] recommended the use of a magnet bonded to the canine and an attracting magnet in a removable acrylic appliance to erupt the impacted canine into occlusion. These authors felt that this replicates normal eruption better than other methods, involves a less invasive surgical procedure, provides for well-controlled spatial guidance, and decreases the hazards of bone loss and root resorption. Sandler[105] also advocated the use of a magnetic system as a modern alternative approach in the eruption of impacted teeth.

Bishara[50] summarized some of the methods of applying traction to an impacted tooth, which includes the use of light wire springs soldered to a heavy labial or palatal base wire, or directly to molar bands, mousetrap loops, or a 'ballista spring'.[22] Some of the newer orthodontic materials have expanded the repertoire of materials which can be very effective in moving an impacted tooth, such as elastic threads, elastomeric chains, nickel titanium springs and nickel titanium wires. The methods of applying a traction force to a palatally displaced canine are now limited only by the imagination of the orthodontist![53,66,97,99,100,106-111]

Early methods of surgical exposure of impacted canines endorsed extensive bone removal to expose the crown of the impacted tooth, mainly for access to place a cast crown or steel ligature on the crown, but also to provide an easier path for tooth movement. The exposure was left open and packed with surgical paste, or a crown form was cemented over the crown of the impacted canine until the soft tissue healed, some natural eruption occurred, and the tooth was then orthodontically brought into occlusion.[53,92]

McDonald and Yap[103] stated that it is not the amount of bone removed that is important, but the manner in which the soft tissues are handled, in particular the periosteum, that ultimately affects the results of the surgical treatment.

In contrast, Kohavi, Becker and Zilberman[111] compared the health of the supporting tissues of impacted canines exposed with a "heavy" exposure or a "light" exposure. They summarized their findings by stating that the most serious damage that occurs in the treatment of palatally impacted canines is the result of surgical intervention which exposes the cementoenamel junction of the impacted tooth. This damage is in the form of loss of supporting tissues, including bone support, of the previously impacted canine.

Today, the two techniques of surgically exposing and bringing the palatally impacted canine into occlusion are the 'open eruption' and the 'closed eruption' techniques. Both techniques require the least amount of bone removal that is necessary to bond an attachment to the crown of the impacted canine.

The open eruption technique is similar to the method used for the last eight decades, except that an attachment is bonded to the tooth, and bone removal and soft tissue excision is minimal. The closed eruption technique, in contrast, has the surgical flap sutured closed after an attachment is bonded on the tooth, with only a ligature wire or gold chain sticking out of the tissue to connect to the elastic force. The wound remains closed as the impacted canine is directed into the arch.

Three papers compared the open eruption technique with the closed eruption technique. In an early publication, Wisth and colleagues[93] compared two groups of patients, all of whom had a Class I malocclusion and required no extractions of permanent teeth. The open eruption group required 18 months of treatment time, while the closed group required 22 months of treatment time. The palatal pocket depth of the closed group was significantly deeper than that in the open group, but the loss of attachment was greater on the palatal side in the open group. The bone height was similar for both groups.

Another group[112] compared only the treatment duration of the two techniques of exposure and found the mean duration to be 28.8 months for both groups. In all subjects, the impaction was categorized by the authors as "intermediate".

In a very recent paper, Burden and his group[113] reviewed the available evidence supporting the two methods of surgical exposure of palatally impacted canines. Their review of the literature failed to produce a clear answer to whether one of the two techniques is better for the long-term health of a palatally impacted canine than the other. The published evidence suggested that repeat surgery can be required with both techniques, but the problem is more often associated with the closed eruption technique, mainly to rebond a loose attachment. The operating time with the closed technique (average time 36 minutes) takes up to three times longer than in the open eruption method (average time 12 minutes). Finally, they found that the delay in applying orthodontic traction often associated with the open technique contributed to a slightly increased period of active orthodontic treatment. This delay in applying traction was usually to allow some free physiologic eruption of the canine to occur before bonding an attachment to the tooth.

1.6.9 - Potential Complications in Treating Palatally Impacted Canines

Studies have indicated ankylosis, loss of attachment, and external resorption as sequelae of orthodontic tooth movement of impacted canines when these teeth are ligated around the cervical area with wire.[21,99] This method of attachment is no longer recommended.

Boyd[96] assessed 20 patients from his own practice, 12 of whom had an attachment direct bonded to the impacted canine, and 8 who had a wire ligated around the cervical area as the method of attachment. All twelve of the direct-bonded patients showed the impacted canine in place at the end of active treatment. In the wire ligation group, 38% of the impacted canines had to be extracted during treatment due to ankylosis and external resorption. In addition, the mean loss of attachment data showed that the direct-bonded group had no clinically significant loss compared to the control teeth, while the wire ligated group did show a clinically significant difference in attachment loss compared to the control group.

A study[114] examining the periodontal status of palatally impacted canines approximately 2 years after active treatment, all aligned using a band cemented to the impacted tooth and using the closed eruption technique, showed that the mean pocket depth was statistically significantly greater in the previously impacted teeth. As well, bone support around the previously impacted canines was significantly less than the control canines, and the previously impacted canines were generally not as well aligned as the control side canines.

Brezniak and Wasserstein[115] published a literature review of factors affecting root resorption and found that the vast majority of reviewed studies reported that severity of root resorption is directly related to treatment duration. If the treatment of impacted canines does indeed take longer than normal, root resorption of any of the teeth could be a potential complication in treating these cases.

Woloshyn et al[116] examined the pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Her group of 32 patients was at least 5 months post-treatment with a mean of 3 years 7 months, and all had a "conservative" surgical exposure with minimal bone removal. These authors found that pocket depths and attachment levels were deeper at the mesial of the previously impacted canine than at the contralateral control site and crestal bone height was significantly lower on the mesial aspect of the impacted canine and distal aspect of the adjacent lateral incisor. Twenty-one percent of the previously impacted canines showed pulpal obliteration at the recall evaluation with twenty-nine percent failing to respond to an electrical pulp test. The roots of the adjacent lateral incisors and premolars were statistically significantly shorter than the contralateral control teeth. Two examiners, viewing intraoral slides, could correctly identify the previously impacted canine in approximately 74% of the cases, due to its discoloration, rotation or slight malposition. They concluded that the periodontal consequences were clinically minimal as long as the exposure was conservative.

Kuftinec and Shapira[117] mentioned that even if the impacted canine has not damaged the roots of the adjacent incisors when orthodontic treatment begins, the orthodontist must be careful when erupting the canine into the arch to not cause iatrogenic resorption by moving the canine into the roots of the adjacent teeth.

Pearson and associates[118] determined that 30.7% of all cases that were exposed and bracketed at the time of surgery, and erupted into occlusion using the closed eruption method, required a second surgical intervention. Only 15.3% of those cases with simple surgical exposure (open-eruption and free physiological eruption for 6-9 months) required a second surgery. They suggested that simple exposure and some time of free physiologic eruption provides an equally efficient and predictable method of managing the palatally impacted canine with clinical and financial benefits, even though this method required 4 extra months of total treatment time.

In a recent Canadian study of both labially and palatally displaced canines[119], a group of researchers observed 54 patients with 82 impacted canines for 18-30 months after surgery. The 60 palatally impacted canines all utilized the closed eruption technique, and the 22 labially displaced teeth employed either an apically repositioned flap or closed eruption, depending on the initial position of the canine. All of the 82 teeth were successfully brought into occlusion. The only complications included 2 palatal and 1 labial canine debonding during treatment. Clinically, there were no cases of infection, eruption failure, ankylosis, gingival inflammation, or gingival recession once complete eruption was achieved.

1.6.10 - Retention Considerations

Becker et al[114] found a higher incidence of rotations or spaces on the previously impacted side in approximately 17% of the cases, compared to about 9% on the control side.

Woloshyn et al[116] reported noticeable post-treatment changes in the previously impacted canines, such as intrusion, lingual displacement, rotation and discoloration in 40% of these teeth. On the contralateral side, 91% of the teeth were in good alignment.

Clark[82] recommended that lingual drift of a previously palatally impacted canine can be prevented by removing a "halfmoon-shaped wedge" of tissue from the lingual of the now aligned tooth. To prevent rotational relapse of these teeth, or any previously rotated tooth, a circumferential supracrestal fiberotomy (CSF) can be performed, or a permanently bonded retainer can be placed.

1.6.11 - Treatment Duration

Studies[120,121] on the evaluation of factors which affect the duration of orthodontic treatment suggest that treatment time can vary widely between offices and in the same office, depending on the particulars of the individual case. Some of the most important factors which explained the variability in treatment duration include: the number of missed appointments, number of extracted premolars, number of brackets and bands replaced or recemented, the necessity of wearing headgear, and the severity of the malocclusion at the start of treatment. The one study[120] which included impacted canines as a variable had nothing to report on its effect on treatment duration.

Published literature[93,112-114,116,118] suggested that the duration of treatment for orthodontic cases involving palatally impacted canines took an average of 18 months to 30 months, with a wide range for individual cases. None of the above studies used a control group to compare treatment duration of non-impacted canine cases from the various offices used. No literature was found which examined whether the initial position of the canine, or whether unilateral or bilateral, had an effect on the treatment duration.

1.6.12 - Panoramic Radiography

Most dentists or orthodontists first locate the palatally impacted canine on the panoramic radiograph and rate the severity of the impaction using this radiograph. Some of the studies on these teeth also used this radiograph to determine the severity of the impaction; the initial angulation of the impacted canine, the position in relation to adjacent teeth, and the distance from the occlusal plane.[39,111,116] The most common reference lines, as established by Ericson and Kurol[39], are the occlusal plane as the horizontal line, and the maxillary dental midline as the vertical line. From these reference lines the relative position of the canine is then reported: angularly to the vertical line and the vertical distance in millimetres from the occlusal plane. Additionally, the position of the canine crown medially relative to the adjacent incisor is established. In the late 1940's, Paatero, a Finish scientist, developed the pantomograph for dental use from the medical process of laminography or body section radiography.[122,123] Pantomography or panoramic radiography projects all images onto a single film without superimposition of the mandibular, maxillary and facial structures.[124,125] A recent survey of American orthodontists[126] revealed that 92% of respondents took panoramic radiographs as a routine pre-treatment orthodontic film. The advantages[125] included the broad anatomic region visible on one film, the relatively low radiation dose, and ease and speed with which the radiograph was made. Disadvantages[125] included the lack of fine detail compared to intraoral films, variable magnification and distortion.

Some degree of distortion is inherent in all panoramic radiographs.[127-132] This occurs because each panoramic machine has a focal trough which conforms to what the company considers the ideal dental arch. Differences from this ideal in size and shape of the skull, jaws and teeth, and asymmetries between right and left sides contribute to distortion.

Christen and Segreto[133], in a study with some of the early panoramic machines, found vertical elongation in the premolar, molar and midramus areas, and shortening in the horizontal dimensions. With the chin raised up 1 cm, the vertical magnification increased slightly but the horizontal shortening was a little less. With the chin lowered 1 cm, there were better results than with the chin raised except in the condylar and coronoid process regions. Moving the chin 1 cm to the right, resulted in an enlarged right side but a decreased left side.

Rowse[128] also investigated the vertical and horizontal distortion in orthopantomograms. He found that different parts of the mandible showed different degrees of magnification and that there was twice as much vertical as horizontal distortion.

In research done with a panoramic machine from the mid-1980's, Larheim and Svanaes[134] found acceptable reproducibility of the left and right sides on images taken at different times, and a consistent 18% to 21% magnification factor for vertical variables. In contrast, they found that measurement of horizontal variables was unreliable because of inconsistent magnification due to a distortion effect caused by both a projection factor and a motion factor.

Common errors made in panoramic radiography are positioning errors and technical errors.[135] Positioning errors occurred with greater frequency than technical errors, with different distortions occurring depending on the error made. The authors emphasized the importance of training in the use of the radiographic equipment to make the best image possible.

In their study, Ursi et al[136] agreed that horizontal measurements are unreliable because they are influenced by a projection factor and a motion factor, but angular measurements are not so variable. They stated that, for clinical purposes, a 5 degree measurement variation between two exposures is not serious.

Using 10 skulls, Carter and colleagues[137] analysed vertical magnification of the midface. Their results showed that as one moves posteriorly around the arch, the magnification increased, from a factor of 1.12 at the median palatal suture to 1.19 at the first molar. They found that small variations in the magnification factor occur with variations in head positioning but this may not be clinically important if the positioning error is small.

Serman and Buch[138] mentioned how the inherent distortions seen in panoramic radiographs can be used to localize impacted teeth. An impacted canine which appeared larger than the contralateral non-impacted canine lay palatal to the dental arch, while an impacted tooth which appeared smaller and more fuzzy or indistinct on the panoramic image than the contralateral canine was positioned labial to the dental arch.

Comparing the accuracy of images from three different panoramic machines and two lateral oblique projections, Wyatt et al[139] found that more accurate vertical and horizontal measurements can be made from the lateral oblique projections, but the angular measurements were similar between the two different radiographic views. The mean vertical measurement differences ranged from 4mm-6mm for the different panoramic machines, while the mean horizontal differences were only 0.1mm-1.6mm, but with a wide range.

Xie et al[140] assessed whether it was possible to make accurate vertical measurements of the jaws from panoramic radiographs. They took 5 skulls and radiographed them in different positions: the ideal position, shifted 5 mm forwards and backwards, and tilted up and down 5 degrees. They found that a line joining the articular eminences is unsuitable as a horizontal reference line for measurements in the tooth-bearing areas. A line using the inferior points of the orbits was unsuitable for measurements in the anterior part of the maxilla in the tilted skulls, but was acceptable in the posterior maxilla. Shifting forwards or backwards by 5 mm had little effect on measurements. They recommended a horizontal reference line that is located anatomically directly above or below the point being measured, in the plane of the centre of the image layer. The occlusal plane line, as used to measure the vertical position of an impacted canine, would fit this recommendation. They concluded by stating that a slight misalignment of the head, such as the 5 degrees or 5 mm that they used, does not significantly affect vertical measurements as long as the reference line is in the same vertical plane as the teeth.

In a companion study, Xie et al[141] found that variations in vertical measurements of dentate subjects were small: 9%-11% for the mandible and 6%-11% for the maxilla. They used the inferior points of the orbit as the reference line for the maxillary measurements.

A recent update on dental imaging by Whaites and Brown[142] suggested that patient positioning aids on current panoramic machines, such as light beam marker lines, make the repeatable and proper positioning of the patient much easier and more accurate. Measurements from computed tomography (CT) imaging are significantly more accurate than those taken from a standard panoramic image, however these machines are currently not priced for purchase by individual practitioners. Digital imaging equipment, which is now available and affordable, will allow a reduction in the radiation dose, and the manipulation and magnification of areas of interest on a radiographic image. This may increase the diagnostic yield available from an image.

The above studies on panoramic machines and images suggested that with proper training and attention to detail, patient positioning can be a repeatable and accurate undertaking. Vertical measurements and angular measurements seem to be more accurate than horizontal ones. It is important to realize that there will be a small magnification and distortion factor, as stated by each manufacturer of individual machines, and this factor will vary somewhat in different areas of the jaw. These small amounts of variation may not be clinically significant in the use of these images for localizing the position of a palatally impacted canine.

1.7 - References

1. Ash AS. Orthodontic significance of anomalies of tooth eruption. Am J Orthod 1957; 43: 559-76.

2. Thilander B, Jakobsson SO. Local factors in impaction of maxillary canines. Acta Odont Scand 1968; 26: 145-68.

3. Massler M, Schour I. Studies in tooth development: Theories of eruption. Am J Orthod Oral Surg 1941; 27: 552-76.

4. Marks SC Jr., Schroeder HE. Tooth Eruption: Theories and Facts. Anatomical Record 1996; 245: 374-93.

5. Sandy JR. Tooth eruption and orthodontic tooth movement. Br Dent J 1992; 172: 141-49.

6. Cahill DR, Marks SC Jr. Tooth eruption: Evidence for the central role of the dental follicle. J Oral Pathol 1980; 9: 189-200.

7. Marks SC Jr., Cahill DR. Experimental study in the dog of the non-active role of the tooth in the eruptive process. Archs Oral Biol 1984; 29: 311-22.

8. Kardos TB. The mechanism of tooth eruption. Br Dent J 1996; 181: 91-95.

9. Wise GE. The biology of tooth eruption. J Dent Res 1998: 77: 1576-79.

10. Mead SV. Incidence of impacted teeth. Int J Orthod 1930; 16: 885-90.

11. Montelius GA. A comparative study of Chinese and Caucasian dentitions. J Dent Res 1932; 12: 931-38.

12. Dachi SF, Howell FV. A survey of 3874 routine full-mouth radiographs. Oral Surg Oral Med Oral Path 1961; 14: 1165-69.

13. Kramer RM, Williams AC. The incidence of impacted teeth. Oral Surg Oral Med Oral Path 1970; 29: 237-41.

14. Shah RM, Boyd MA, Vakil TF. Studies of permanent tooth anomalies in 7886 Canadian individuals. I: Impacted teeth. J Canad Dent Assoc 1978; 44: 262-64.

15. Grover PS, Lorton L. The incidence of unerupted permanent teeth and related clinical cases. Oral Surg Oral Med Oral Path 1985; 59: 420-25.

16. Jacoby H. The etiology of maxillary canine impactions. Am J Orthod 1983; 84: 125-32.

17. Röhrer A. Displaced and impacted canines. Int J Orthod Oral Surg 1929; 15: 1003-20.

18. Hitchin AD. The impacted maxillary canine. Br Dent J 1956; 100: 1-12.

19. Nordenram A, Strömberg C. Positional variations of the impacted upper canine. Oral Surg Oral Med Oral Path 1966; 22: 711-14.

20. Johnston WD. Treatment of palatally impacted canine teeth. Am J Orthod 1969; 56: 589-96.

21. Fournier A, Turcotte J-Y, Bernard C. Orthodontic considerations in the treatment of maxillary impacted canines. Am J Orthod 1982; 81: 236-39.

22. Jacoby H. The "ballista spring" system for impacted teeth. Am J Orthod 1979; 75: 143-51.

23. Wolf JE, Mattila K. Localization of impacted maxillary canines by panoramic tomography. Dentomaxillofac Radiol 1979; 8: 85-91.

24. Ericson S, Kurol J. Radiographic examination of ectopically erupting maxillary canines. Am J Orthod Dentofac Orthop 1987; 91: 483-92.

25. Broadbent BH. Ontogenic development of occlusion. Angle Orthod 1941; 11: 223-41.

26. Lappin MM. Practical management of the impacted maxillary cuspid. Am J Orthod 1951; 37: 769-78.

27. Kuftinec MM, Shapira Y. The impacted maxillary canine: I. Review of concepts. ASDC J Dent Children 1995; 62: 317-24.

28. Dewel BF. Clinical observations on the axial inclination of teeth. Am J Orthod 1945; 35: 98-115.

29. Dewel BF. The upper cuspid: Its development and impaction. Angle Orthod 1949; 19: 79-90.

30. Ericson S, Kurol J. Radiographic assessment of maxillary canine eruption in children with clinical signs of eruption disturbance. Eur J Orthod 1986; 8: 133-40.

31. Ericson S, Kurol J. Longitudinal study and analysis of clinical supervision of maxillary canine eruption. Commun Dent Oral Epidemiol 1986; 14: 172-76.

32. Coulter J, Richardson A. Normal eruption of the maxillary canine quantified in three dimensions. Eur J Orthod 1997; 19: 171-83.

33. Fernández E, Bravo LA, Canteras M. Eruption of the permanent upper canine: A radiologic study. Am J Orthod Dentofac Orthop 1998; 113: 414-20.

34. Shafer WG, Hine MK, Levy BM. A textbook of oral pathology, 2nd ed., Philadelphia, WB Saunders, 1963; pp 2-75.

35. Becker A. The orthodontic treatment of impacted teeth. St. Louis, MI, Mosby, 1998; pp 169.

36. Linge BO, Linge L. Apical root resorption in upper anterior teeth. Eur J Orthod 1983; 5: 173-83.

37. Sasakura H, Yoshida T, Murayama S, Hanada K, Nakajima T. Root resorption of upper permanent incisor caused by impacted canine. Int J Oral Surg 1984; 13: 299-306.

38. Ericson S, Kurol J. Incisor resorption caused by maxillary cuspids: A radiographic study. Angle Orthod 1987; 57: 332-45.

39. Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. Am J Orthod Dentofac Orthop 1988; 94: 503-13.

40. Ericson S, Kurol J. CT diagnosis of ectopically erupting maxillary canines - a case report. Eur J Orthod 1988; 10: 115-20.

41. Linge L, Linge BO. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. Am J Orthod Dentofac Orthop 1991; 99: 35-43.

42. Brin I, Becker A, Zilberman Y. Resorbed lateral incisors adjacent to impacted canines have normal crown size. Am J Orthod Dentofac Orthop 1993; 104: 60-66.

43. Rabie A-BM, Deng YM, O'Donnell D, Fanny WWL. Treatment of a palatally impacted canine accompanied by root resorption of incisors: A case report. Quintessence Int 1996; 27: 473-78.

44. Shellhart WC, Jasper S, Abrams H, Wilson T. Case Report: Management of significant incisor root resorption associated with maxillary canine impaction. Angle Orthod 1996; 68: 187-92.

45. Masseler M, Malone A. Root resorption in human permanent teeth: A roentgenographic study. Am J Orthod 1954; 40: 619-33.

46. Becker A, Zilberman Y, Tsur B. Root length of lateral incisors adjacent to palatally-displaced maxillary cuspids. Angle Orthod 1984; 54: 218-25.

47. Garn SM, Lewis AB, Vicinus JH. Third molar polymorphism and its significance to dental genetics. J Dent Res 1969; 48: 1314.

48. Sain DR, Hollis WA, Togrye AR. Correction of a superiorly displaced impacted canine due to a large dentigerous cyst. Am J Orthod Dentofac Orthop 1992; 102: 270-76.

49. Moyers RE. Handbook of Orthodontics, 2nd ed., Chicago, Year Book Medical Publishers, 1963, pp 83-88.

50. Bishara SE. Clinical management of impacted maxillary canines. Semin Orthod 1998; 4: 87-98.

51. Becker A, Smith P, Behar R. The incidence of anomalous lateral incisors in relation to palatally displaced cuspids. Angle Orthod 1981; 51: 24-29.

52. Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. Angle Orthod 1994; 64: 249-56.

53. Fastlicht S. Treatment of impacted canines. Am J Orthod 1954; 40: 891-905.

54. Takahama Y, Aiyama Y. Maxillary canine impaction as a possible microform of cleft lip and palate. Eur J Orthod 1982; 4: 275-77.

55. Brin I, Solomon Y, Zilberman Y. Trauma as a possible etiologic factor in maxillary canine impaction. Am J Orthod Dentofac Orthop1993; 104: 132-37.

56. McConnell TL, Hoffman DL, Forbes DP, Janzen EK, Weintraub NH. Maxillary canine impaction in patients with transverse maxillary deficiency. ASDC J Dent Child 1996; 63: 190-95.

57. Shah RM, Boyd MA, Vakil TF. Studies of permanent tooth anomalies in 7886 Canadian individuals. II. Congenitally missing, supernumerary and peg teeth. J Canad Dent Assoc 1978; 6: 265-68.

58. Miller BH. The influence of congenitally missing teeth on the eruption of the upper canine. Dent Pract 1963; 13; 497-504.

59. Brin I, Becker A, Shalhav M. Position of the maxillary permanent canine in relation to anomalous or missing lateral incisors: a population study. Eur J Orthod 1986; 8: 12-16.

60. Zilberman Y, Cohen B, Becker A. Familial trends in palatal canines, anomalous lateral incisors, and related phenomena. Eur J Orthod 1990; 12: 135-39.

61. Mossey PA, Campbell HM, Luffingham JK. The palatal canine and the adjacent lateral incisor: A study of a west of Scotland population. Br J Orthod 1994; 21: 169-74.

62. Oliver RG, Mannion JE, Robinson JM. Morphology of the maxillary lateral incisor in cases of unilateral impaction of the maxillary canine. Br J Orthod 1989; 19: 9-16.

63. Becker A. Palatal canine displacement: Guidance theory or an anomaly of genetic origin? Letter to the editor with a response from Peck S, Peck L, and Kataja M. Angle Orthod 1995; 65: 95-102.

64. Kay LW. The impacted maxillary canine - Part I. Dent Update 1977; 4: 335-39.

65. Ferguson JW. Management of the unerupted maxillary canine. Br Dent J 1990; 169: 11-17.

66. Usiskin LA. Management of the palatal ectopic and unerupted maxillary canine. Br J Orthod 1991; 18: 339-46.

67. Alling CC. Impacted canine teeth. Dent Clin N Amer 1979; 23: 439-50.

68. Williams BH. Diagnosis and prevention of maxillary canine impaction. Angle Orthod 1981; 51: 30-40.

69. Hunter SB. The radiographic assessment of the unerupted maxillary canine. Br Dent J 1981; 150: 151-55.

70. Fox NA, Fletcher GA, Horner K. Localising maxillary canines using dental panoramic tomography. Br Dent J 1995; 179: 416-20.

71. Jacobs SG. Localisation of the unerupted maxillary canine. Aust Orthod J 1986; 9: 311-16.

72. Jacobs SG. Localisation of the unerupted maxillary canines: further observations. Aust Orthod J 1988; 10: 247-51.

73. Jacobs SG. Localisation of the unerupted maxillary canine: additional observations. Aust Orthod J 1994; 13: 71-75.

74. Jacobs SG. The impacted maxillary canine. Further observations on aetiology, radiographic localization, prevention/interception of impaction, and when to suspect impaction. Aust Dent J 1996; 41: 310-16.

75. Jacobs SG. Localization of the unerupted maxillary canine: How to and when to. Am J Orthod Dentofac Orthop 1999; 115: 314-22.

76. Ngan PW, Wolf T, Kassoy G. Early diagnosis and prevention of impaction of the maxillary canine. ASDC J Dent Child 1987; 54: 335-38.

77. Ericson S, Kurol J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. Eur J Orthod 1988; 10: 283-95.

78. Jacobs SG. Reducing the incidence of palatally impacted maxillary canines by extraction of deciduous canines: a useful preventive/ interceptive orthodontic procedure. Case reports. Aus Dent J 1992; 37: 6-11.

79. Jacobs SG. Palatally impacted canines: aetiology of impaction and the scope for interception. Report of cases outside the guidelines for interception. Aus Dent J 1994; 39: 206-11.

80. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. Br J Orthod 1993; 20: 215-23.

81. Easthope DW. Presurgical recovery of palatally impacted canines. Aus Dent J 1982; 27: 94-97.

82. Clark D. The management of impacted canines: free physiologic eruption. JADA 1971 82: 836-40.

83. Öhman I, Öhman A. The eruption tendency and changes of direction of impacted teeth following surgical exposure. Oral Surg Oral Med Oral Path 1980; 49: 383-89.

84. Altman JA, Arnold H, Spector P. Substituting maxillary first premolars for maxillary impacted canines in cases requiring the extraction of dental units as part of orthodontic correction. Am J Orthod 1979, 75: 618-29.

85. Freeman RS. Adult treatment with removal of all four permanent canines. Am J Orthod Dentofac Orthop 1994; 106: 549-54.

86. Slagsvold O, Bjercke B. Auto-transplantation of premolars with partly formed roots. Am J Orthod 1974; 66: 355-66.

87. Sagne S, Lennartsson B, Thilander B. Transalveolar transplantation of maxillary canines. An alternative to orthodontic treatment in adult patients. Am J Orthod Dentofac Orthop 1986; 90: 149-57.

88. Tang ELK. Multispecialty team management of a case with impacted maxillary permanent canines. ASDC J Dent Child 1992; May-June; 190-95.

89. Schatz J-P, Joho JP. A clinical and radiologic study of autotransplanted impacted canines. Int J Oral Maxillofac Surg 1993; 22: 342-46.

90. McKay C. The unerupted maxillary canine. An assessment of the role of surgery in 2500 treated cases. Br Dent J 1978; 145; 207-10.

91. Hunter SB. Treatment of the unerupted maxillary canine. Part 1 - Preliminary considerations and surgical methods. Br Dent J 1983; 154: 294-96.

92. Strock MS. A new approach to the unerupted tooth by surgery and orthodontics. Am J Orthod 1938; 24: 626-34.

93. Wisth PJ, Norderval K, Bøe OE. Comparison of two surgical methods in combined surgical-orthodontic correction of impacted maxillary canines. Acta Odont Scand 1976; 34: 53-57.

94. Lewis PD. Preorthodontic surgery in the treatment of impacted canines. Am J Orthod 1971; 60; 382-97.

95. Sly WJ. Unerupted or impacted maxillary cuspid: report of a case. Am J Orthod 1950; 36: 913-16.

96. Boyd RL. Clinical assessment of injuries in orthodontic movement of impacted teeth. I. Methods of attachment. Am J Orthod 1982; 82: 478-86.

97. Ziegler TF. A modified technique for ligating impacted canines. Am J Orthod 1977; 72: 665-70.

98. von der Heydt K. The surgical uncovering and orthodontic positioning of unerupted maxillary canines. Am J Orthod 1975; 68: 256-76.

99. Bishara SE, Kommer DD, McNeil MH, Montagano LN, Oesterle LJ, Youngquist HW. Management of impacted canines. Am J Orthod 1976; 69: 371-87.

100. Stangl DP. Conservative treatment of palatally impacted canines. Am J Orthod 1976; 69: 328-34.

101. Becker A, Zilberman Y. A combined fixed-removable approach to the treatment of impacted maxillary canines. J Clin Orthod 1975; 9: 162-69.

102. Orton HS, Garvey MT, Pearson MH. Extrusion of the ectopic maxillary canine using a lower removable appliance. Am J Orthod Dentofac Orthop 1995; 107: 349-59.

103. McDonald F, Yap WL. The surgical exposure and application of direct traction of unerupted teeth. Am J Orthod 1986; 89: 331-40.

104. Vardimon AD, Graber TM, Drescher D, Bourauel C. Rare earth magnets and impaction. Am J Orthod Dentofac Orthop 1991; 100: 494-512.

105. Sandler JP. An attractive solution to unerupted teeth. Am J Orthod 1991; 100: 489-93.

106. Gensior AM, Strauss RE. The direct bonding technique applied to the management of the maxillary impacted canine. JADA 1974; 89: 1332-37.

107. Becker A, Zilberman Y. The palatally impacted canine: A new approach to treatment. Am J Orthod 1978; 74: 422-29.

108. Kuftinec MM, Shapira Y. The impacted maxillary canine. II. Orthodontic considerations and management. Quintessence Int 1984; 9: 921-26.

109. Meyers CE. Extrusion of palatally impacted cuspids. J Clin Orthod 1985; 19: 664-65.

110. Magnusson H. Saving impacted teeth. J Clin Orthod 1990; 24: 246-49.

111. Crescini A, Clauser C, Giorgetti R, Cortellini P, Pini Prato GP. Tunnel traction of infraosseous impacted maxillary canines. A three year periodontal follow-up. Am J Orthod Dentofac Orthop 1994; 105: 61-72.

112. Iramaneerat S, Cunningham SJ, Horrocks E. The effect of two alternative methods of canine exposure upon subsequent duration of orthodontic treatment. Int J Ped Dent 1998; 8: 123-29.

113. Burden DJ, Mullally BH, Robinson SN. Palatally ectopic canines: Closed eruption versus open eruption. Am J Orthod Dentofac Orthop 1999; 115: 634-39.

114. Becker A, Kohavi D, Zilberman Y. Periodontal status following the alignment of palatally impacted canine teeth. Am J Orthod 1983; 84:332-36.

115. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. Am J Orthod Dentofac Orthop 1993; 103: 138-46.

116. Woloshyn H, Årtun J, Kennedy DB, Joondeph DR. Pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Angle Orthod 1994; 64: 257-64.

117. Kuftinec MM, Shapira Y. The impacted maxillary canine: II. Clinical approaches and solutions. ASDC J Dent Child 1995; 62: 325-34.

118. Pearson MH, Robinson SN, Reed R, Birnie DJ, Zaki GA. Management of palatally impacted canines: the findings of a collaborative study. Eur J Orthod 1997; 19: 511-15.

119. Caminiti MF, Sandor GKB, Giambattistini C, Tompson B. Outcomes of the surgical exposure, bonding and eruption of 82 impacted maxillary canines. J Can Dent Assoc 1998; 64: 572-79.

120. Fink DF, Smith RJ. The duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1992; 102: 45-51.

121. Beckwith RF, Ackerman RJ, Cobb CM, Tira DE. An evaluation of factors affecting duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1999; 115: 439-47.

122. Paatero YV. The use of a mobile source of light in radiology. Acta Radiol 1948; 29: 221-27.

123. Paatero YV. A new tomographic method for radiographing curved outer surfaces. Acta Radiol 1949; 32: 177-84.

124. Graber TM. Panoramic radiography. Radiography 1966; 36: 293-311.

125. Goaz PW, White SC. Oral Radiology: Principles and Interpretations, 2nd ed., CV Mosby Co., St. Louis, 1987.

126. Gottlieb EL, Nelson AH, Vogells DS. 1990 JCO study on orthodontic diagnosis and treatment procedures. J Clin Orthod 1991; 25: 145-56.

127. Turner KO. Limitations of panoramic radiography. Oral Surg Oral Med Oral Path 1968; 26: 312-20.

128. Rowse CW. Notes on interpretation of the orthopantomogram. Br Dent J 1971; 130: 425-34.

129. Samfors KA, Welander U. Angle distortion in narrow beam rotation radiography. Acta Radiol 1974; 15: 570-76.

130. Frykholm A, Malmgren O, Samfors KA, Welander U. Angular measurements in orthopantomography. Dentomaxillofac Radiol 1977; 6: 77-81.

131. Tronje G, Welander U, McDavid WD, Morris CR. Image distortion in rotational panoramic radiography. Acta Radiol 1981; 22: 585-92.

132. Samawi SSB, Burke PH. Angle distortion in orthopantomograms. Br J Orthod 1984; 11: 100-07.

133. Christen AG, Segreto VA. Distortion and artifacts encountered in Panorex radiography. JADA 1968; 77: 1096-1101.

134. Larheim TA, Svanaes DB. Reproducibility of rotational panoramic radiography: Mandibular linear dimensions and angles. Am J Orthod Dentofac Orthop 1986; 90: 45-51.

135. Schiff T, D'Ambrosio J, Glass BJ, Langlais RP, McDavid WD. Common positioning and technical errors in panoramic radiography. JADA 1986; 113: 422-26.

136. Ursi WJS, Almeida RR, Tavano O, Henriques JFC. Assessment of mesiodistal axial inclination through panoramic radiography. J Clin Orthod 1990; 24: 166-73.

137. Carter LC, Dennison M, Carter JM. Panoramic zonography of the midface: A clinician's guide to vertical magnification. Today's FDA 1990; 2(12): 1C-3C.

138. Serman NJ, Buch B. Localization of impacted teeth utilizing inherent panoramic distortions. Annals Dent 1992; 51: 8-10.

139. Wyatt DL, Farman AG, Orbell GM, Silveira AM, Scarfe WC. Accuracy of dimensional and angular measurements from panoramic and lateral oblique radiographs. Dentomaxillofac Radiol 1995; 24: 225-31.

140. Xie Q, Soikkonen K, Wolf J, Mattila K, Gong M, Ainamo A. Effect of head positioning in panoramic radiography on vertical measurements: an *in vitro* study. Dentomaxillofac Radiol 1996; 25: 61-66.

141. Xie Q, Wolf J, Ainamo A. Quantitative assessment of vertical heights of maxillary and mandibular bones in panoramic radiographs of elderly dentate and edentulous subjects. Acta Odont Scand 1997; 55: 155-61.

142. Whaites E, Brown J. An update on dental imaging. Br Dent J 1998; 185: 166-72.

143. Chaushu S, Chaushu G, Becker A. The use of panoramic radiographs to localize displaced maxillary canines. Oral Surg Oral Med Oral Path Oral Radiol Endod 1999; 88: 511-16.

Chapter Two

Research Paper #1

Reliability of Panoramic Reference Lines Used in Describing the Position of Palatally Impacted Maxillary Canines: A Pilot Study

2.1 - Introduction

A recent survey of American orthodontists revealed that 92% of respondents took panoramic radiographs as a routine pre-treatment orthodontic film.[1] Some degree of distortion is inherent in all panoramic radiographs due to differences in size and shape of the skull, jaws and teeth, and asymmetries between right and left sides.[2-8] In the sharply depicted layer of the panoramic radiograph the image will show the same magnification factor for both the horizontal and vertical planes.[9] Objects outside this layer will appear distorted because of a motion factor - the difference between the velocity of the film and the velocity of the projection of the object on the film.[9] Displacement, distortion and magnification can cause changes in the dimensions and position of objects on radiographs compared to the actual object.

A 1968 study using some of the early panoramic machines found vertical elongation in the premolar, molar and midramus areas, and shortening in the horizontal dimension.[10] With the chin raised up 1 cm, the vertical magnification increased slightly but horizontal shortening was less. With the chin lowered 1 cm, there were better results than with the chin raised except in the condylar and coronoid process regions. Moving the chin 1 cm to the right resulted in an enlarged right side and smaller left side. Another investigation into vertical and horizontal distortion in orthopantomograms found that different parts of the mandible showed different degrees of magnification and that there was twice as much vertical as horizontal distortion.[3]

In research done with panoramic machines from the mid-1980's, Larheim and Svanaes[11] found acceptable reproducibility of the left and right sides on images taken at different times, and an 18% to 21% magnification factor for vertical variables. In contrast, they found that measurement of horizontal variables was unreliable because of inconsistent magnification due to a distortion effect caused by both a projection factor and a motion factor.

Another investigation[12] agreed that horizontal measurements are unreliable because of the influence of the projection factor and motion factor, but angular measurements were not so variable. They stated that, for clinical purposes, a 5 degree measurement variation between two exposures is not serious.

Using 10 skulls, Carter and colleagues[13] analysed vertical magnification of the midface. Their results showed that as one moves posteriorly around the arch the magnification increased, from a factor of 1.12 at the median palatal suture to 1.19 at the first molar. They found that small variations in the magnification factor occurred with variations in head positioning but this may not be clinically important if the positioning error is small.

Xie et al[14] assessed the accuracy of vertical measurements taken from panoramic radiographs. It was found that a line joining the articular eminences was unsuitable as a horizontal reference line for measurements in the tooth-bearing areas. A line using the inferior points of the orbits was unsuitable for measurements in the anterior part of the maxilla in the tilted skulls, but was acceptable in the posterior maxilla. Shifting forwards or backwards by 5 mm had little effect on measurements. These authors recommended a horizontal reference line that is located anatomically directly above or below the point being measured, in the plane of the centre of the image layer. The occlusal plane line when used to measure the position of an impacted canine would fit this recommendation. They concluded by stating that a slight misalignment of the head, such as the 5 degrees vertical tipping or 5 mm transverse movement that they used, does not significantly affect vertical measurements as long as the reference line is in the same vertical plane as the teeth.

Common errors made in panoramic radiography are positioning errors and technical errors.[15] Positioning errors occurred with greater frequency than technical errors, with different distortions occurring depending on the error made. A recent update on dental imaging suggested that patient positioning aids on current panoramic machines, such as light beam marker lines, make the repeatable and proper positioning of the patient much easier and more accurate.[16]

Most dentists or orthodontists first locate a palatally impacted canine on a panoramic radiograph and assess the severity of the impaction from this radiograph. This assessment often determines whether to extract the impacted canine or attempt to orthodontically bring it into occlusion. Some investigators who studied impacted canines used this radiograph to determine the severity of the impaction and to describe the initial angulation of the impacted tooth, the horizontal position in relation to adjacent teeth, and the vertical distance from the occlusal plane.[17-19]

Common reference lines used in studies of impacted canines, as established by Ericson and Kurol[17], are the occlusal plane as the horizontal line, and the midline of the maxillary central incisors as the vertical line. From these reference lines the relative position of the canine is reported; the angle of impaction relative to the vertical line, position of the crown medially relative to the adjacent incisor, and distance from the occlusal plane.

The objective of this panoramic radiographic study was to determine what effects 5° rotations of dried skulls about vertical and horizontal axes would have on a metal marker affixed to the palate in the approximate position of an impacted maxillary canine. The occlusal plane and a vertical line bisecting the long axes of the maxillary central incisors were used as reference lines. The repeatability and reliability of these reference lines in studies of impacted canines have not been previously reported.

2.2 - Materials and Methods

A sample of 5 adult dry skulls with intact maxillary dentitions was obtained from the collection of the Faculty of Medicine and Dentistry at the University of Alberta. A metal marker in the shape of a cross, fabricated from .036 inch orthodontic wire, was temporarily affixed to the skulls on the right palatal side of the maxilla in the approximate location that an impacted canine would be located. All of the panoramic radiographs were made in the Division of Radiology at the University of Alberta. Each skull was stabilized in the headholder of a Siemens Orthophos 100 orthopantomographic machine (Siemens Corporation, Iselin N.J.) with the radiation beam attenuated to provide an acceptable exposure of the dried skulls. Each skull was radiographed five times, once in each of five different positions. The initial radiograph was made with the skull's Frankfort horizontal plane aligned with the horizontal light beam marker of the panoramic machine, the midline of the skull aligned with the vertical light beam marker, and the maxillary central incisors placed into the bite tab of the machine (the ideal view). Radiographs were then taken with the skull rotated 5° up and 5° down (up and down views) while keeping the midline of the skull on the vertical light beam marker. Two additional radiographs were made with the skull rotated 5° to either side about a vertical axis (left and right views) while keeping Frankfort horizontal aligned with the horizontal light beam marker of the panoramic unit. These 5° rotation marks were previously placed on the skulls with a removable marker using a standard protractor. Foramen magnum was used as the vertical axis centre of rotation, while the external auditory meatus was used as the horizontal axis of rotation. In order to minimize movement of the skull within the head holder of the panoramic unit the ideal view was always done first, followed by the vertical projections. The left and right views were done last. Each radiograph was processed and labelled before the next projection was taken.

These five different radiographic projections of each of the five skulls were viewed under standardized conditions and traced onto acetate overlays using a 0.3 mm diameter lead pencil. Each radiograph was traced and measured twice, at least one week apart, by the principal investigator.

On each tracing the occlusal plane reference line was drawn, connecting the mesiobuccal cusp of the maxillary first permanent molar and the incisal edge of the maxillary central incisor on the side that the metal marker was placed. A vertical reference line was drawn bisecting the long axes of the two maxillary central incisors (Figure 2.1). From these two reference lines linear measurements were made using electronic calipers accurate to 1/100 of a millimetre (Digimatic Caliper, Mitutoyo

Corp., Japan), and angular measurements were made using a protractor accurate to 1°.

Four linear and two angular measurements were performed. Using the occlusal plane reference line, measurements were made vertically along the long axis of the metal marker to the closest point of the metal marker and the furthest point of the metal marker. Two separate measurements were done to determine whether a larger distance from the reference line would show a different error than a shorter distance. From the vertical reference line, two horizontal measurements were made along the horizontal long axis of the metal marker to the closest and furthest points of the metal marker. In addition, angular measurements were made using the vertical reference line and both the horizontal and vertical portions of the metal marker. (Figure 2.1)

Subsequently, the radiographic distortion for the different measurements with different head rotations was calculated. The measurements with the skulls placed in the ideal position were established at 100%, and distortion factors for the different skull positions were calculated. (Table 2.3)

2.3 - Statistical Analysis

All twenty-five radiographs were used for statistical analysis using the SPSS 9.0 statistical package (SPSS for Windows, SPSS Inc, Chicago, Ill). To determine the tracing and measurement error of the linear and angular variables, all radiographs were randomly traced twice and each tracing was measured twice. The average measurement value and standard deviation of each linear and angular measure was determined over the four repeated measurements. Subsequently, the mean standard deviation of each linear and angular variable for all five skulls was calculated using 25 measurements –

the 5 different skulls and 5 different positions (Table 2.1). The mean differences of the measurements between the different rotations of the skulls were calculated and the statistical significance of these differences was assessed using a paired two-tailed t-test (Table 2.2). Significance levels less than 5% were considered to be statistically significant.

2.4 - Results

Descriptive data for the mean values and standard deviations (SD), paired t-tests and p-values, and distortion factors for the different variables can be found in Tables 2.1 through 2.3. The t-tests revealed that there were significant differences in the values of some linear and angular variables for different 5° rotations of each skull when compared to a properly placed skull.

The variable 'Horizontal 1' did not show any statistical differences in the measurements for the different positions. The 'Vertical Angle' and 'Vertical 2' variables had the greatest amount of measurement variation with 7 of the 10 positional comparisons showing a statistically significant difference. Generally, any comparison between a right rotation and any other rotation showed a significant difference in the measurement values. The largest measurement difference tended to be between the left and right positions, with the ideal/down comparison generally showing the smallest measurement variability.

Table 2.3 shows the distortion factors of different positions for the different variables compared to the value for the ideal position. These values are not to be confused with the amount of magnification which actually occurs on the panoramic radiograph in the anterior area. These distortion factors are only in comparison to the value of the measurement when the skull is properly placed in the radiographic machine.

Generally, a left rotation resulted in a slight increase in the measurement values while a right rotation resulted in a decrease in the values. The vertical movements commonly showed smaller variability in their values compared to the value in the ideal position than the left and right rotations did.

2.5 - Discussion

The purpose of this study was to determine if various measurements done in the anterior maxilla in the approximate location of a palatally impacted canine, employing reference lines used in other studies involving impacted maxillary canines, will be reliable even with small rotations of the head in the panoramic machine. It was not the purpose to determine the amount of actual magnification which may occur in the anterior maxilla in panoramic radiographs. Because it was a pilot study, the number of subjects was small and should be kept in mind when interpreting the results. Another limitation was that the metal marker was placed on the palatal surface of the maxilla and not inside the alveolus where an actual impacted canine would be located. This could have an affect on the magnification and measurements involved as the marker may have been outside the focal trough, which would result in more blurring, distortion and magnification than objects within the focal trough.[20]

When an object is placed perpendicular to the central ray of the radiographic tube, its projected height in a panoramic radiograph is at a maximum.[21] When the same object is inclined towards the film or towards the tube, its projected height will change non-linearly with respect to the angle of the tilt.[21] Similarly, when an object is horizontally rotated towards or away from the film in a panoramic machine, its position will appear to change on the radiograph depending on the direction of head rotation. Xie et al[14] have suggested that vertical measurements in the anterior maxilla from reference lines which are not in the same vertical plane as the anterior maxillary teeth, such as from a line joining the articular eminences or one joining the zygomatic arches, are sensitive to up/down tilting of the skull. Horizontal measurements on panoramic radiographs are not reliable when compared to the actual measurement due to a distortion effect caused by a projection factor and a motion factor.[11] Carter et al[13] found that small variations in the magnification factor occur with variations in head positioning but that this may not be clinically important if the positioning error is small. Angular measurements have shown less variability on panoramic radiographs compared to linear measurements.[11,12,22]

In this study the only variable which did not show any statistical difference of the means for any of the skull positions was the linear measure 'Horizontal 1'. In general, the further the linear distance to the point of interest, the more the measurements varied for the different skull movements. In all cases, except 'Horizontal 1' and 'Horizontal Angle', there was a difference in the measures between the left and right skull rotations. The horizontal measurements were generally greater as the skull was rotated to the left and smaller with a right rotation, compared to the ideal position, especially with the larger distances of 'Horizontal 2'. This occurred because the metal marker, which was placed on the right side of the maxilla in all five skulls, was magnified in size with a right rotation and would thus appear closer to the midline. The opposite effect occurred with a left rotation where the metal marker appeared to be decreased in size and further from the midline. The 10° difference between a 5° rotation right and a 5° rotation left would be expected to cause a variance in the measurements due to the different magnification which would occur with the different skull positions. The distance for the 'Horizontal 1' measurement is small and was not as affected by magnification as much as the longer distance for the 'Horizontal 2' measurement, where the measurement point was in a different part of the maxilla. This agreed with studies which found that different parts of the jaws have different magnification factors.[3,11,13]

Similarly, values between the vertical movements might be expected to show variability, especially for the vertical variables measured, due to the 10° change in skull position. It was found that 'Vertical Angle' and the large distance in 'Vertical 2' do indeed show a statistically significant difference in their measures with the different skull rotations. The shorter distances involved in 'Vertical 1' did not show a statistically significant difference but generally showed a trend, with a larger value for the down position and a smaller value for the up position.

Angular measurements of the vertical marker (Vertical Angle) appeared to be more affected by head movements than those of the horizontal marker (Horizontal Angle), with more of the Vertical Angle measures showing significant differences from each other. This may be due to the vertical part of the marker being in the area of the canine, which has a different magnification factor than the central incisor area where the reference line was situated.[13]

Measurement differences between the ideal position and the down position were not significantly different for any of the linear or angular variables. This was in agreement with Christen and Segreto[10] who found that distortions were generally less with a slight (1 cm) downward position of the chin compared to a slight upward position of the chin.

Xie et al[14] have recommended a horizontal reference plane located directly above or below the point being measured. The metal marker in this study was palatal to the teeth used as points for the horizontal reference line, therefore additional error, compared to measurements of an actual impacted canine which would be closer to the plane of the line of reference and the focal trough of the panoramic machine, could have been introduced.

With only one exception, the standard deviations of the averages of linear measures were less than 10% of the total value, and the angular variables less than 3° (Table 2.1). For clinical purposes, a variation in measurement of up to 5° between two exposures is not considered serious.[5,7,12] The mean difference of the measurements for the different variables measured, between the different skull positions, generally varied by less than 1 mm for the shorter distances and less than 3 mm for the longer distances, with the angular differences generally less than 3° (Table 2.2). As seen in Table 2.3, the distortion of the measurements with slight skull rotations commonly varied by 10% or less compared to the measurements on an ideally positioned skull. In the context of describing the position of a palatally impacted maxillary canine these differences may not be clinically significant.

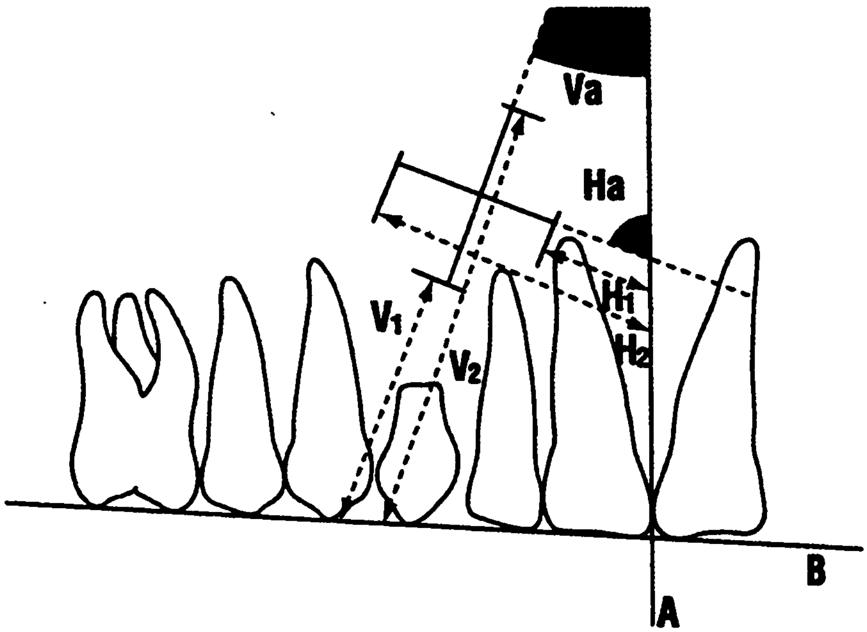
Papers on palatally impacted canines describe the horizontal position of an impacted canine in relation to the adjacent teeth and do not use horizontal linear measurements.[17,19,23] This may be due to the superior descriptive value in stating the canine crown position relative to the adjacent incisor as it is easier to assess the orthodontic difficulty involved with a canine which is fully overlapping the lateral incisor root as opposed to a canine which is 12 mm from the midline. This method also removes the effect of unreliable horizontal measurements on panoramic radiographs.[11,22] There could be some distortion in the position of the canine relative to the adjacent incisor with this method if there is a large positioning error in the panoramic machine, due to the slightly different buccal-lingual positions of the canine and adjacent incisor (the buccal shift rule).

Stating the distance from the occlusal plane, which is the vertical distance needed to erupt the canine into occlusion, allows the orthodontist to assess the severity of the impaction in this dimension. Taking into account the radiographic magnification of individual panoramic machines, a measurement error of 1-3 mm is probably not clinically significant.

2.6 - Conclusion

Most modern panoramic machines have patient positioning aids, such as light beam markers, to aid in the repeatable, correct placement of the patients. With correct training and the use of these positioning aids, accurate panoramic radiographs should be able to be made on a consistent basis. A slight misalignment of the head (within 5° of ideal) results in statistically different horizontal, vertical and angular measurements to describe palatally impacted canine position using occlusal plane and mid-sagittal vertical reference lines. These sources of error should be considered in research design. Whether or not the level of error introduced by patient positioning variations (within 5°) represents clinical significance should also be considered.

Figure 2.1 Reference Lines, Linear and Angular Variables



Schematic illustration of a tracing from a panoramic radiograph. Vertical reference line (midline) (A); Horizontal reference line (Occlusal Plane) (B); Vertical distance 1 (V_1); Vertical distance 2 (V_2); Horizontal distance 1 (H_1); Horizontal distance 2 (H_2); Vertical angle (Va); Horizontal angle (Ha).

Table 2.1 **Average values and mean SD as determined through study of 5 skulls rotated through 5 positions***

Skull and Position	Vertical 1 mm	Vertical 2 mm	Horizontal 1 mm	Horizontal 2 mm	Vertical Angle deg	Horizontal Angle deg
1 Ideal	9.3	27.3	7.9	27.8	18.3	81.8
1 Left	10.1	27.9	9.1	28.1	20.5	79.0
1 Right	8.1	25.0	9.1	26.1	16.8	80.0
1 Down	10.1	28.8	7.7	27.5	21.5	78.0
1 Up	8.4	26.0	8.7	30.6	17.5	84.3
2 Ideal	4.2	22.4	8.3	25.2	15.3	89.0
2 Left	4.8	23.2	7.7	26.1	16.5	91.8
2 Right	3.6	20.9	7.4	20.9	13.5	88.8
2 Down	4.4	22.5	7.8	23.3	14.5	90.5
2 Up	4.1	21.3	8.0	26.0	13.8	94.0
3 Ideal	3.8	22.1	9.0	25.4	5.3	92.0
3 Left	4.7	23.6	7.9	27.5	7.0	93.0
3 Right	3.8	22.0	8.8	24.6	5.5	92.0
3 Down	4.3	22.6	8.9	25.4	7.0	89.0
3 Up	3.7	21.7	8.8	27.5	3.8	95.5
4 Ideal	6.6	24.3	12.3	29.6	14.3	84.5
4 Left	7.0	25.0	12.7	31.7	15.8	86.0
4 Right	6.0	22.7	11.5	26.0	12.5	82.3
4 Down	6.9	25.0	12.9	30.3	15.8	81.3
4 Up	6.5	23.9	12.4	30.0	13.5	86.5
5 Ideal	9.9	28.6	9.6	25.8	30.8	74.0
5 Left	11.5	31.5	8.4	25.3	34.3	73.0
5 Right	9.0	26.0	9.1	22.7	28.8	68.5
5 Down	9.6	28.3	9.6	25.1	30.0	69.0
5 Up	9.6	27.8	9.7	25.8	29.3	74.8
Mean SD	0.62	1.22	0.50	1.72	1.64	2.44
SD of the SD	0.26	0.53	0.16	0.41	0.43	0.28

*Average values determined from 2 tracings and 2 measurements of each tracing. Mean SD determined over 25 measurements (5 different skulls and 5 different positions).

Table 2.2 Differences between means and p-values for the different measurement variables and skull rotations

Variable	Positions	Mean Difference	SD	p-value*	Variable	Positions	Mean Difference	SD	p-value*
Vertical 1	Id/Lt	-0.87(mm)	0.45	0.200	Horizontal 2	Id/Lt	-0.99(mm)	1.13	0.121
	Id/Rt	0.65	0.41	0.024*		Id/Rt	2.66	1.44	0.014*
	Lt/Rt	1.52	0.68	0.007*		Lt/Rt	3.65	1.65	0.008*
	Id/Dn	-0.30	0.41	0.181		Id/Dn	0.44	0.91	0.337
	Id/Up	0.30	0.30	0.088		Id/Up	-1.25	1.17	0.075
	Dn/Up	0.60	0.65	0.107		Dn/Up	-1.69	1.38	0.052
	Lt/Dn	0.57	0.74	0.330		Lt/Dn	1.43	1.04	0.037*
	Lt/Up	1.17	0.57	0.010*		Lt/Up	-0.26	1.48	0.714
	Rt/Dn	-0.95	0.59	0.023*		Rt/Dn	-2.22	1.35	0.021*
	Rt/Up	-0.35	0.29	0.056		Rt/Up	-3.91	0.91	0.001*
Vertical 2	Id/Lt	-1.31(mm)	0.97	0.039*	Vertical Angle	Id/Lt	-2.05(deg)	0.89	0.007*
	Id/Rt	1.62	0.95	0.019*		Id/Rt	1.35	0.91	0.030*
	Lt/Rt	2.93	1.51	0.012*		Lt/Rt	3.40	1.44	0.006*
	Id/Dn	-0.49	0.70	0.193		Id/Dn	-1.00	1.73	0.266
	Id/Up	0.82	0.42	0.012*		Id/Up	1.20	0.41	0.003*
	Dn/Up	1.31	0.92	0.033*		Dn/Up	2.20	1.46	0.028*
	Lt/Dn	0.82	1.53	0.300		Lt/Dn	1.05	2.10	0.325
	Lt/Up	2.12	0.94	0.007*		Lt/Up	3.25	1.05	0.002*
	Rt/Dn	-2.12	1.19	0.017*		Rt/Dn	-2.35	1.61	0.031*
	Rt/Up	-0.81	0.82	0.091		Rt/Up	-0.15	2.00	0.775
Horizontal 1	Id/Lt	0.23(mm)	1.04	0.647	Horizontal Angle	Id/Lt	-0.30(deg)	2.21	0.780
	Id/Rt	0.24	0.84	0.565		Id/Rt	1.94	2.21	0.120
	Lt/Rt	0.01	0.87	0.987		Lt/Rt	2.24	2.23	0.088
	Id/Dn	0.02	0.43	0.914		Id/Dn	2.70	2.47	0.071
	Id/Up	-0.11	0.43	0.583		Id/Up	-2.76	1.59	0.018*
	Dn/Up	-0.14	0.55	0.612		Dn/Up	-5.46	1.21	<0.001*
	Lt/Dn	-0.21	1.03	0.677		Lt/Dn	3.00	1.72	0.017*
	Lt/Up	-0.34	0.75	0.366		Lt/Up	-2.46	1.76	0.035*
	Rt/Dn	-0.21	1.04	0.671		Rt/Dn	0.76	1.89	0.420
	Rt/Up	-0.35	0.55	0.227		Rt/Up	-4.70	1.08	<0.001*

* A p-value of 0.050 or less is considered statistically significant. P-values determined from paired two-tailed t-tests. Id=Ideal position. Lt=5° Left rotation. Rt=5° Right rotation. Dn=5° Down rotation. Up=5° Up rotation.

Table 2.3 Average distortion factors for the measured variables compared to the ideal position

Skull Position		Vertical 1	Vertical 2	Horizontal 1	Horizontal 2	Vertical Angle	Horizontal Angle
Ideal Position		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
5° Left		112.9%	105.2%	97.6%	103.7%	112.2%	100.4%
Rotation	SD	6.6%	3.9%	11.0%	4.2%	5.3%	2.6%
5° Right		90.3%	93.5%	97.5%	90.0%	91.9%	97.7%
Rotation	SD	6.1%	3.8%	8.9%	5.4%	5.4%	2.6%
5° Down		104.4%	102.0%	99.8%	98.3%	106.0%	96.8%
Rotation	SD	6.1%	2.8%	4.5%	3.4%	10.3%	2.9%
5° Up		95.6%	96.7%	101.2%	104.7%	92.8%	103.3%
Rotation	SD	4.4%	1.7%	4.5%	4.4%	2.5%	1.9%

2.7 - References

1. Gottlieb EL, Nelson AH, Vogells DS. 1990 JCO study on orthodontic diagnosis and treatment procedures. J Clin Orthod 1991; 25: 145-56.

2. Turner KO. Limitations of panoramic radiography. Oral Surg Oral Med Oral Path 1968; 26: 312-20.

3. Rowse CW. Notes on interpretation of the orthopantomogram. Br Dent J 1971; 130: 425-34.

4. Samfors KA, Welander U. Angle distortion in narrow beam rotation radiography. Acta Radiol 1974; 15: 570-76.

5. Frykholm A, Malmgren O, Samfors KA, Welander U. Angular measurements in orthopantomography. Dentomaxillofac Radiol 1977; 6: 77-81.

6. Tronje G, Welander U, McDavid WD, Morris CR. Image distortion in rotational panoramic radiography. I. General considerations. Acta Radiol 1981; 22: 585-92.

7. Samawi SSB, Burke PH. Angle distortion in orthopantomograms. Br J Orthod 1984; 11: 100-07.

8. Graber TM. Panoramic radiography. Angle Orthod 1966; 36: 293-311.

9. Amir C, Asja C, Melita V-P et al. Evaluation of the precision of dimensional measurements of the mandible on panoramic radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998; 86: 242-48.

10. Christen AG, Segreto VA. Distortion and artifacts encountered in Panorex radiography. JADA 1968; 77: 1096-1101.

11. Larheim TA, Svanaes DB. Reproducibility of rotational panoramic radiography: Mandibular linear dimensions and angles. Am J Orthod Dentofac Orthop 1986; 90: 45-51.

12. Ursi WJS, Almeida RR, Tavano O, Henriques JFC. Assessment of mesiodistal axial inclination through panoramic radiography. J Clin Orthod 1990; 24: 166-73.

13. Carter LC, Dennison M, Carter JM. Panoramic zonography of the midface: A clinician's guide to vertical magnification. Today's FDA 1990; 2(12): 1C-3C.

14. Xie Q, Soikkonen K, Wolf J, Mattila K, Gong M, Ainamo A. Effect of head positioning in panoramic radiography on vertical measurements: an *in vitro* study. Dentomaxillofac Radiol 1996; 25: 61-66.

15. Schiff T, D'Ambrosio J, Glass BJ, Langlais RP, McDavid WD. Common positioning and technical errors in panoramic radiography. JADA 1986; 113: 422-26.

16. Whaites E, Brown J. An update on dental imaging. Br Dent J 1998; 185: 166-72.

17. Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. Am J Orthod Dentofac Orthop 1988; 94: 503-13.

18. Woloshyn H, Årtun J, Kennedy DB, Joondeph DR. Pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Angle Orthod 1994; 64: 257-64.

19. Crescini A, Clauser C, Giorgetti R, Cortellini P, Pini Prato GP. Tunnel traction of infraosseus impacted maxillary canines. A three-year periodontal follow-up. Am J Orthod Dentofac Orthop 1994; 105: 61-72.

20. Welander U, McDavid W, Tronje G, Morris CR. An analysis of different planes within the image layer in rotational panoramic radiography. Dentomaxillofac Radiol 1987; 16: 79-84.

21. Tronje G, Eliasson S, Julin P, Welander U. Image distortion in rotational panoramic radiography. II. Vertical distances. Acta Radiol 1981; 22: 449-55.

22. Wyatt DL, Farman AG, Orbell GM, Silveira AM, Scarfe WC. Accuracy of dimensional and angular measurements from panoramic and lateral oblique radiographs. Dentomaxillofac Radiol 1996; 25: 61-66.

23. Power SM, Short MBE. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. Br J Orthod 1993; 20: 215-23.

Chapter Three

Research Paper #2

Factors Relating to Treatment Duration of Palatally Impacted Maxillary Canines

3.1 - Introduction

It is recognized that efficient office management and success in orthodontic practice requires an accurate prediction of treatment duration. Two of the first questions asked by patients and their parents are "How long will I need to wear my braces?" and "How much is all this going to cost?" Patients whose treatment is finished "on time" may be more satisfied and may be more likely to refer other patients for orthodontic treatment. An accurate prediction of treatment duration and the number of office visits needed to treat a case will allow efficient control of office overhead and enable the orthodontist to better determine an acceptable fee.

The canine is the second most commonly impacted tooth after the third molar with the rate of maxillary canine impaction ranging from approximately 1% to 3%.[1-6] Palatal displacement of the maxillary canine is more common than labial displacement, with studies showing a highly variable ratio of 2:1 to 9:1 for palatal:labial canine impactions.[6-13] Once a palatally impacted maxillary canine has been diagnosed and localized, and any preventive/interceptive measures have failed in normalizing the position of the tooth, some type of active treatment is indicated. There are many proposed treatment alternatives for the correction of the palatally impacted canine in the literature. Consideration needs to be given to the attitude of the patient, the space present at the canine site and in the arches generally, the general state of the dentition, mobility and/or resorption of adjacent teeth, the position of the canine, the presence of a root dilaceration of the impacted canine, the age and health of the patient, and surgical difficulties and/or contraindications to surgery. The more common methods of treating a patient with a palatally displaced maxillary canine, as summarized by Bishara[14], include: 1) no treatment, 2) extraction of the impacted canine and movement of the first premolar into its position, 3) extraction of the impacted canine and prosthetic replacement of the canine, 4) extraction of the canine and a segmental osteotomy to move the buccal segment mesially to close the space, 5) surgical exposure, allowing natural eruption to occur, 6) autotransplantation of the impacted canine, and 7) surgical exposure of the canine with orthodontic treatment to bring the canine into proper occlusion.

Palatally impacted maxillary canines often present a treatment planning quandary for the clinical orthodontist. They are considered to be an important tooth esthetically and functionally, but impacted maxillary canine cases are perceived to be more difficult and time consuming than the average orthodontic case. Should one try to bring the impacted tooth into the arch, expecting that this procedure will add extra time and expense to an average treatment, or does one extract the offending tooth, thus saving time and money for the patient but perhaps at the expense of acceptable esthetics and long-term function? Estimation of treatment duration in these cases is currently based entirely upon subjective clinical experience. The examination of factors which may have an influence on the duration of orthodontic treatment in impacted maxillary canine cases would be beneficial to both orthodontists and orthodontic patients.

Studies of factors which affect the duration of orthodontic treatment suggest that treatment time can vary widely between offices and in the same office, depending on the particulars of the individual case.[15,16] Published literature[17-22] suggests that the duration of treatment for orthodontic cases involving palatally impacted canines can take an average of 18 months to 30 months, with a wide range for individual cases. None of the above studies involving impacted canines used a control group to compare treatment duration of non-impacted canine cases from the various offices used. No literature was found which examined whether the initial position of the canine as seen on a panoramic radiograph, or whether a unilateral or bilateral canine impaction, has an effect on treatment duration.

The purpose of this retrospective study was to examine whether the A-P position, vertical position, and angulation of a palatally impacted maxillary canine, as seen on a panoramic radiograph, have any relation to the duration of orthodontic treatment in an adolescent sample. In addition, this study will examine whether a difference in treatment duration exists between bilateral and unilateral palatally impacted canine cases.

3.2 - Materials and Methods

This retrospective observational study analyzed patient records collected from three private orthodontic offices which used preadjusted, preangulated and pretorqued orthodontic appliances with a 0.022 inch slot.

The selection criteria for inclusion in the study included the following: adolescents less than 20 years of age requiring full fixed orthodontic appliances, with the presence of at least one palatally impacted maxillary canine and who attended their orthodontic appointments regularly, as determined by clinical notes; treatment which was completed non-extraction, with 6 mm or less of initial crowding in either arch; and patient records, including complete diagnostic and treatment notes, pre-treatment and post-treatment panoramic radiographs, lateral cephalometric radiographs, photographs, models, banding/bonding date, debanding/debonding date, and a surgical referral letter stating the presence and surgical exposure date of at least one palatally impacted canine. Some of the patients may have had a course of Phase I treatment but the date of complete banding/bonding was considered the start date for this study. In all, data from 47 subjects was collected which fulfilled all of the criteria; thirteen each from two offices, and twenty-one from a third office (Table 3.1).

The variable of interest was the treatment duration. The independent variables examined which may have had an effect on treatment duration were the patient gender, side of the canine impaction, distance from the occlusal plane of the canine crown, canine inclination, zone of the canine crown, Angle's classification of occlusion, amount of maxillary and mandibular crowding, overjet and overbite.

Angle's classification of the first permanent molars and initial crowding was determined from a subjective assessment of pre-treatment models, with reference to photographs and clinical notes. Overjet and overbite were measured from the pre-treatment lateral cephalogram using a millimetre ruler accurate to 1 millimetre.

All pre-treatment panoramic radiographs were viewed under standardized conditions and traced onto acetate tracing paper using a 0.3 mm diameter lead pencil. Reference lines consisting of a horizontal occlusal plane reference line and a vertical line, bisecting the long axes of the maxillary central incisors, modified from the method described by Ericson and Kurol[23], were drawn on each tracing. Previous research has shown that these reference lines have an angulation error of ±3° and linear error ±10% of the measured distance when used to describe the location of an impacted canine on panoramic radiographs where the patient is positioned within 5° of ideal.[24]

Using these lines, the canine inclination to the vertical reference line, the vertical distance to the canine tip measured perpendicularly from the occlusal plane reference line, and the A-P position of the canine tip in relation to adjacent teeth (the 'zone') were recorded (adapted from Ericson and Kurol[23], Figure 3.1). Zone 1 is the normal A-P position, between the first bicuspid and the lateral incisor, that the permanent canine would occupy during its normal eruption. Zone 2 is the area from the distal edge of the lateral incisor crown to its midpoint. Zone 3 is the area from the midpoint of the lateral incisor to the distal edge of the central incisor crown. Zone 4 is the area from the distal edge of the central incisor crown to its midpoint. Zone 5 is the area from the midpoint of the central incisor to the maxillary dental midline (Figure 3.1). The inclination of the impacted tooth was calculated using a standard protractor accurate to 1 degree, while the vertical distance from the occlusal plane was measured with digital calipers accurate to 1/100th of a millimetre (Digimatic Caliper, Mitutoyo Corp., Japan).

A control group was randomly collected to match as closely as possible the demographics of the study group, with the exception of the impacted canine. The variables used in matching the control group to the impacted canine group included adolescents less than 20 years of age requiring full fixed, non-extraction orthodontic treatment, gender, amount of initial maxillary and mandibular crowding, Angle's classification of occlusion, overjet and overbite. This control sample was used for comparing treatment duration to the impacted canine sample (Table 3.2).

3.3 - Analysis of Data

Statistical analyses were done using the SPSS 9.0 statistical package (SPSS for Windows, SPSS Inc, Chicago, Ill). Differences between the samples from the three offices used were evaluated by a oneway analysis of variance (ANOVA) for each variable. The only variable showing a statistically significant difference between the three offices was age, with all the offices showing a large standard deviation for this variable. Charts collected from one of the offices had five of the total six subjects who were 200 months (16.6 years) or older, which skewed that office's mean age to be higher than the other two offices. The impacted canine subjects from all three offices were combined into one group for statistical analysis and comparison to the control sample. For subjects with bilateral impactions, only data from the more severely displaced canine (furthest from the occlusal plane, a greater angulation, more medially displaced) was used in the analyses, reasoning that bringing this tooth into final occlusion would dictate the ultimate treatment time.

To determine the error of tracing, landmarking and measurement of the angular and linear panoramic values, five panoramic radiographs were randomly traced five times each, at least one day apart. Each tracing was measured twice, also at least one day apart. The determination of error for overjet and overbite measurements was accomplished by taking lateral cephalographs from five patients and randomly tracing them five times each and measuring twice, with at least one day between successive tracings and measurements.

The intra-examiner reliability for the description of initial crowding present was determined by the principal investigator taking maxillary and mandibular models from 10 patients and subjectively rating the amount of crowding on two separate occasions, at least one month apart. Inter-examiner reliability for the amount of crowding present was determined by comparing the results of the principal investigator to three other examiners, using maxillary and mandibular models from 5 patients. Two of the examiners were faculty members in the Department of Graduate Orthodontics at the University of Alberta, while the other was a senior orthodontic resident.

To determine variables of significance relating to the treatment duration of the impacted canine group various statistical tests were used. Further investigation used correlation statistics to determine any relation between the different variables.

3.4 – Results

Intra-rater reliability for the panoramic measurements showed a very high correlation with r-values greater than 0.990 (p-values < .000) for both angular and linear measurements, with no differences in category placement for 'zone' in the repeated tracings. The correlation values for the repeated measurements of OJ and OB were r = 0.960 and r = 0.924 (p-values < .000) respectively. Correlation values of r = 0.934 (p-value < .000) for the maxillary crowding and r = 0.967 (p-value < .000) for the mandibular crowding were found for intra-rater reliability, and r = 0.962 and r = 0.923 (p-values < .000) respectively, for inter-rater reliability.

Tables 3.2 and 3.3 show the comparisons and demographics of the control group and impacted canine group. Twenty-nine of the total forty-seven impacted canine subjects had a unilateral impaction (61.7%) while eighteen presented with bilateral impaction (38.3%) of the maxillary canines, for a total of 65 palatally impacted canines. Thirty-two of the impacted canines were located on the left side (49.2%) while thirty-three (50.8%) were found on the right. Thirty (64%) of the subjects presented with a Class I occlusion, fourteen (30%) with a Class II tendency, and three (6%) with a Class III tendency.

The only significant differences between the control group and the impacted canine group for the variables measured were the age at the start of treatment (p-value $< .000$) and treatment duration (p-value $< .000$) (Table 3.2). The average treatment duration for the impacted canine group as a whole was 28.3 months with a range of 13 months to 50 months. The unilateral palatally impacted canine group averaged 25.8 months with a range of 13 months to 40 months, while the average treatment duration for the bilaterally impacted canines group was 32.3 months, with a range of 23 months to 50 months. The control group showed an average treatment time of 22.4 months, with a range from 10 months to 41 months.

3.4.1 - Variables of Interest for the Impacted Canine Group (Tables 3.4 to 3.10)

Linear Regression Results and Correlations (Tables 3.4 and 3.5)

Linear regression indicated that the only variables of significance with 'Length of Treatment' as the dependent variable were the age of the patient and the amount of mandibular crowding that was present at the beginning of treatment. A linear regression model with 'Age' and 'Md crowding' as the independent variables explained 30% of the variation in treatment duration (Table 3.4). However, the Pearson correlation analysis revealed many variables that had significant relationships to one another (Table 3.5). There was a negative correlation between the age of the patient and the distance the impacted canine was from the occlusal plane (correlation coefficient = -0.520, p-value < .000). Age was also negatively correlated with the length of orthodontic treatment (correlation = -.471, p-value = .001). Overjet and overbite were related with an increased overjet being found with an increased overbite (correlation = .469, p-value = .001). The amount of crowding in the mandibular arch was positively correlated with the amount of crowding present in the maxillary arch (correlation = 0.493, p-value < .000).

The distance the impacted canine was from the occlusal plane was related to the inclination it had (correlation = .409, p-value = .004), and the A-P position (or zone) that it was in (correlation = -.378, p-value = .009). The distance from the occlusal plane was also correlated to the age of the patient (correlation = -.520, p-value < .000) and the duration of treatment (correlation = .424, p-value = .003).

Unilateral vs Bilateral Impactions (Tables 3.6 and 3.7, Figure 3.2)

An independent samples t-test comparing the impacted canines in the unilateral impaction subjects and the most severely impacted canines in the bilateral impacted canine subjects revealed that the length of treatment was significantly different between the two groups (p-value = .006). Additionally, the differences in the distance from the occlusal plane was very close to statistical significance with a p-value = 0.051.

3.5 - Discussion

Previous studies on the duration of orthodontic treatment[15,16,25,26] have found that some of the most important factors relating to treatment time include the number of missed appointments, number of replaced brackets and bands, number of treatment phases, number of negative chart entries regarding oral hygiene, the wearing of headgear, number of extracted premolars, pretreatment mandibular plane angle, pretreatment ANB angle, age at the start of treatment, and pretreatment Salzmann Index (which includes teeth that are missing, crowded, rotated, blocked out, spaced, Angle's occlusion, crossbites, open-bites, OB and OJ[15]). Even so, the amount of variability in treatment duration explained by these studies ranges from only 24.9% to a high of 53.6%.[15,16,25,26] Fink and Smith[15] reported that they could explain 50% of the variation in treatment duration with a five-step multiple regression equation, but close examination of their data shows that R equalled 0.499 and R^2 was 0.249. Thus, they actually explained only 24.9% of the variation in treatment duration with their regression equation.

Some of the variation in treatment duration in both the impacted canine and the control groups in this investigation would be due to the factors mentioned above from other studies which have evaluated duration of orthodontic treatment.[15,16,25,26] However, the impacted canine group will have the additional element of bringing the impacted tooth (or teeth) into alignment from its palatal position. The interest was to determine if this element could be accomplished during the time frame that a general non-extraction treatment would take.

The control group in this study started treatment at age 12.9 years compared to 14.4 years for the impacted canine sample. This may be due to palatally impacted canines frequently not being noticed until a somewhat older age because the rest of the dentition often displays only a mild malocclusion or crowding problem, and a palatally impacted canine may not be noticed by the patient or diagnosed by the general dentist until after the age of 12 – 14 years when it normally would erupt.

The treatment time of the non-extraction control sample in this study averaged 22.4 months. This can be compared to previous studies which showed an average treatment time for non-extraction patients to range from 19 months to 31 months.[15,16,25,26]

The length of treatment for the unilateral palatally impacted canine group in this investigation averaged 25.8 months. This is approximately 4 months longer than the average treatment duration of the non-impacted canine control group in this study, and is less than some of the treatment duration averages for general non-extraction cases in other studies.[16,26] However, the individual treatment times for the impacted canine group showed a very large range, and when rationalizing that impacted canine cases take significantly longer than 'average' orthodontic cases, clinicians may be remembering those cases that took 35 or 40 months. They may not remember as vividly those impacted canine cases that took only 16 or 20 months.

The 32.3 months average duration of treatment for the bilateral impacted canine cases was over 6 months longer than for the unilateral cases. Part of this variation in treatment duration could be attributable to the fact that the most severely impacted canines in the bilateral group were in a moderately significantly worse position than those in the unilateral impacted group. Why this occurred was not explained. The sample size of eighteen for the bilateral group was not large and this result could be due to chance, or canines in bilateral cases may be more severely impacted than those in unilateral cases. A bilateral impaction may be a more severe expression of a genetic disorder and is expressed with a more severely impacted tooth. The reasoning that the most severely displaced canine would dictate treatment duration in a bilateral impacted canine case seems to be a reasonable assumption. However, there may also be other factors involved which affected the treatment duration of the bilateral impacted canine cases compared to the unilateral impacted canine cases that were not addressed in this study. Further research to determine other factors which may be related to this variation in treatment duration are required.

Besides the bilateral/unilateral impaction comparison, the only two significant factors relating to the duration of treatment in impacted canine cases investigated in this study were the age of the patient at the start of orthodontic treatment, and the amount of mandibular arch crowding present at the start of treatment.

The greater the amount of mandibular crowding present at the start of treatment, the longer the duration of orthodontic treatment. This is in agreement with studies which found that the initial malocclusion has a relation to treatment duration[15] but disagrees with other investigations which did not find a relation between the initial severity of the malocclusion and duration of orthodontic treatment.[27] However, these other studies looked at more than just the amount of crowding to determine the severity of the initial malocclusion. All of the subjects in this study had what can be considered a relatively mild amount of crowding of less than 6 mm and all were treated non-extraction.

Surprisingly, the younger the patient in the impacted canine group, the longer the duration of orthodontic treatment. Those who started treatment under age 12 years took on average over 35 months to treat, while those who were 18 years of age or older at the beginning of treatment averaged only 20.8 months of treatment (Table 3.8). This may be due to the fact that the younger patients had a more severely impacted canine than the older ones. The Pearson correlation analysis showed that there was a negative correlation between the age of the patient and the distance the canine was from the occlusal plane. This correlation analysis also suggested that as the canine was positioned further from the occlusal plane, it had a greater inclination and was more medially displaced.

It may be that palatally impacted maxillary canines improve their position over time. As the canine continues to erupt in its ectopic location inside the maxillary alveolus, albeit very slowly, anatomical constraints or perhaps a genetic component, may allow it to improve its position to some extent. This possible positional improvement over time results in orthodontic treatment started at a later age to be on a less severely positioned tooth and consequently treatment may take less time.

Another possible explanation for the difference in the severity of impaction of the canine in the different age groups may be the referral pattern of general dentists. Perhaps general dentists adopt a 'wait and see' approach with less severely impacted canines, and if they do not erupt in at a later age the patient is then referred to the orthodontist. With the more severely impacted canines the dentists may refer the case as soon as they are seen.

Initial Position of the Impacted Canine (Figure 3.2, Tables 3.9 and 3.10)

In this study, the displacement of the impacted canines in the vertical dimension ranged from 6.4 mm to 20.9 mm from the occlusal plane. The patients were grouped into six sub-groups with an almost equal number of patients in each group. A boxplot was generated with length of treatment on the y-axis and the six groupings on the x-axis, and a non-parametric Kruskal-Wallis test was run on the different groupings. This test showed that the treatment durations were statistically significantly different amongst the groups (p-value = .027), while visual analysis of the boxplot suggested that there was a difference between groups 1 and 2, and the rest of the groups. The data was then grouped into only two groupings, combining groups 1 and 2 into one group, and combining the rest of the groups into one group. A Mann-Whitney test was then done between these two groupings. This analysis showed that there is a significant difference in treatment duration for those patients who have an impacted canine at less than 14.0 mm from the occlusal plane, and those patients with a canine impacted at greater than 14.0 mm (p-value = .001, Table 3.10). Those impacted canines less than 14.0 mm from the occlusal plane averaged 23.8 months of treatment time, while those greater than 14.0 mm averaged 31.1 months of treatment time. A possible explanation is that the greater the distance one needs to erupt the canine into the arch, the longer treatment will take. The third dimension, the antero-posterior direction in the anterior maxilla, can not be seen on a panoramic radiograph and this distance may be greater with a more vertical displacement of the canine. With 3-D radiographic techniques just beginning to be explored in dental radiography, perhaps we will be better able to represent the true position of an impacted canine in the near future and better understand how this position is related to treatment duration.

Whatever the reason may be, 14.0 mm seems to be a dividing line between a shorter and much longer treatment time. Indeed, only 4 of the total 29 cases (13.8%) in the >14.0 mm group had individual treatment times less than the average for the <14.0 mm group (23.8 months). Two cases had a 17 month treatment duration, one required 22 months and one took 23 months. Only 3 of the 18 (16.7%) cases with the canine <14.0 mm showed individual treatment times longer than the average for the >14.0 mm cases (31.1 months). These cases showed 33, 34 and 35 month treatment times, with the 33 month case at 13.9 mm from the occlusal plane.

The two-dimensional A-P position of an impacted canine as seen on a panoramic radiograph was related to the distance from the occlusal plane and the inclination of the tooth. The more medially positioned the canine, the higher up in the alveolus and the more horizontally angulated it was found to be. This may be related to the development and eruption of the canine and anatomy and shape of the maxilla in this area. The canine erupts in a mesial direction from its point of development and only begins to upright at about age 9 years, either due to genetic control or due to the guidance of the lateral incisor.[28-30] As the canine erupts down towards the arch it must become more vertical due to the presence of other teeth and their roots in the area and the pyramidal shape of the maxillary alveolus itself. However, if the canine is too far medially displaced it may not be able to upright because of these same constraints.

3.6 - Conclusion

On the basis of the results of this study of 47 subjects showing the presence of at least one palatally impacted maxillary canine, and a matched control sample of 47 subjects without an impacted canine, the following conclusions may be drawn:

1) Unilateral impaction cases took 4 months longer to treat than the non-impacted canine control cases.

2) Bilateral impaction cases took over 6 months longer to treat than the unilateral impaction cases. Part of the reason may have been that the most severely impacted canines in bilateral cases were more severely impacted than the canines in the unilateral cases.

3) The greater the distance the impacted canine was from the occlusal plane, the greater the angulation and more medially displaced it was.

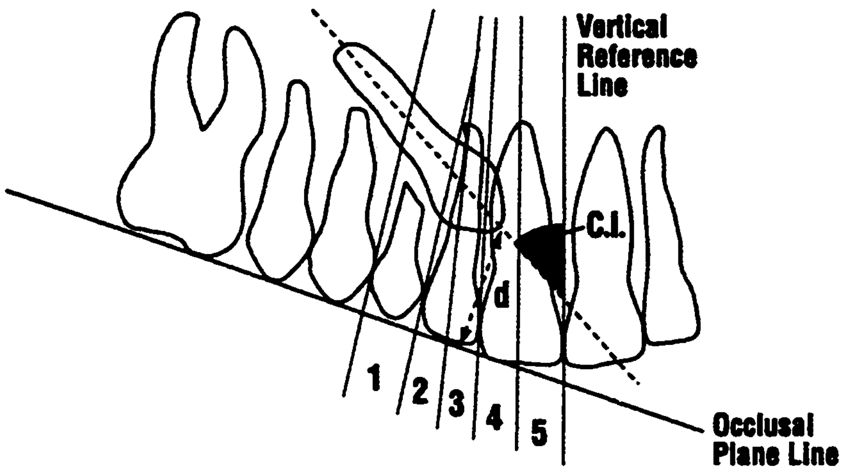
4) The younger the patient at the start of treatment, the longer the duration of orthodontic treatment.

5) The younger the patient, the more severely displaced was the impacted canine. This may mean that impacted canines have some capacity to self-correct with time, at least to a limited extent.

6) When the impacted canine crown was at a distance from the occlusal plane of <14 mm, treatment time averaged 23.8 months, while a distance >14 mm took an average of 31.1 months of treatment time.

The general area of research into factors affecting orthodontic treatment duration is still relatively new and requires additional studies to more accurately determine the causes of variation in treatment time for all types of orthodontic malocclusions, including impacted canine cases.

Figure 3.1 - Reference Lines, Linear and Angular Measurements



Canine inclination (C.I.) to the midline, Distance (d) from the occlusal plane line, and Zone (1-5) of the impacted canine.

Table 3.1 - Inter-office comparisons for the impacted canine group

Office	n	Variable	Minimum	Maximum	Mean	SD
1	13	Age (years)	12.6	19.3	14.3	1.9
		Length of Tx (months)	20.0	50.0	27.7	8.9
		Mx crowding (mm)	-4.0	+6.0	-0.2	2.3
		Md crowding (mm)	-4.0	+3.0	-0.5	1.7
		OJ (mm)	2.0	5.0	3.4	0.8
		OB (mm)	1.0	5.0	3.5	1.2
2	13	Age (years)	10.9	19.5	15.7	2.7
		Length of Tx (months)	13.0	35.0	27.9	6.4
		Mx crowding(mm)	-5.0	+3.0	-1.7	2.0
		Md crowding (mm)	-5.0	0.0	-1.4	1.4
		OJ (mm)	2.0	4.0	2.5	0.7
		OB (mm)	1.0	6.0	3.8	1.7
3	21	Age (years)	10.3	15.7	13.6	1.6
		Length of Tx (months)	17.0	48.0	28.9	8.9
		Mx crowding (mm)	-4.0	+5.0	-0.8	2.2
		Md crowding (mm)	-5.0	0.0	-1.5	1.8
		OJ (mm)	0.0	6.0	3.1	1.6
		OB (mm)	0.0	6.0	3.5	1.7

Table 3.2 – Comparison of Impacted Canine Group and Control Group

		Gender	Age (years)	Length of Tx (mos)	Molar Relation	Mx Crowding (mm)	Md Crowding (mm)	OJ (mm)	OB (mm)
Impacted Canine Group	Mean	F=30 M=17	14.4	28.3	E/E=16 Cl I=28	-0.9	-1.1	3.0	3.6
	SD		2.2	8.2	Sup I=3	2.2	1.6	1.2	1.5
Control Group	Mean	F=28 M=22	12.9	22.4	E/E=17 Cl I=30	-0.5	-1.3	3.2	3.2
	SD		1.2	6.9	Sup I=3	3.0	2.9	1.7	2.1
p-value		.295	<.000*	<.000*	.897	.482	.726	.581	.340

* A p-value of less than .050 is considered statistically significant. P-values for 'Gender' and 'Molar Relation' were determined from Chi-square tests, while the rest of the p-values were determined from independent sample t-tests. E/E = End-to-End molar relation, Cl I = Class I, and Sup I = Super Class I molar relation.

Table 3.3 – Positional distribution of the 65 palatally impacted canines

CI (degrees)	n	Distance (mm)	n	Zone	n	Others
< 15	6	< 10.0	7	1	5	18 - bilateral 29 - unilateral
16-25	21	10.0-11.9	11	2	11	
26-35	15	12.0-13.9	11	3	21	32 - Left 33 - Right
36-45	13	14.0-15.9	18	4	16	
46-55	5	16.0-17.9	14	5	12	30 – Class I 14 – End-to-End 3 – Super Cl I
>55	5	>17.9	4			
Total	65		65		65	

CI = Canine Inclination. Distance = Distance from the Occlusal Plane.

Table 3.4 – Linear Regression Results with Length of Treatment as the dependent variable

Variable	R	R^2	p-value
Age	0.471	0.222	0.001
Age, Md Crowding	0.549	0.301	0.000

Table 3.5 – Pearson Correlation coefficients and p-values between variables for The Impacted Canine Group

		Inclin	Distance from OP	Horizontal Distance	Age	Length of Tx	Mx	Md	OJ	OB
Inclin	Correlat	1.000	.409**	-.649**	-.070	.007	.063	.234	-.136	-.065
	p-value	.	.004	<.000	.640	.965	.676	.113	.362	.666
Distance from OP	Correlat		1.000	-.378**	-.520**	.424**	-.121	.031	.043	.012
	p-value		.	.009	<.000	.003	.419	.834	.776	.938
Horizont Distance	Correlat			1.000	.236	-.039	-.045	-.100	.141	-.196
	p-value			.	.110	.795	.762	.506	.346	.186
Age	Correlat				1.000	-.471**	.042	-.036	-.345*	-.063
	p-value				.	.001	.778	.811	.018	.676
Length of Tx	Correlat					1.000	-.055	-.265	.324*	.107
	p-value					.	.713	.072	.027	.476
Mx	Correlat						1.000	.493**	.166	.048
	p-value						.	<.000	.265	.747
Md	Correlat							1.000	-.008	-.052
	p-value							.	.957	.730
OJ	Correlat								1.000	.469*
	p-value								.	.001
OB	Correlat									1.000
	p-value									.

** Pearson Correlation is significant at the 0.01 level (2-tailed).
* Pearson Correlation is significant at the 0.05 level (2-tailed).
Inclin=Inclination. OP=Occlusal Plane. Horizontal Distance is from the midline. Mx=amount of maxillary crowding. Md=amount of mandibular crowding. OJ=Overjet. OB=Overbite.

Table 3.6 – Control Group vs Unilateral and Bilateral Canine Impactions

	n	Length of Treatment (months)*	SD
Control Group	47	22.4	6.9
Canine Group	47	28.3	8.2
Unilateral	29	25.8	7.0
Bilateral	18	32.3	8.5

* denotes average for this variable.

Table 3.7 – Independent Samples t-tests - Unilateral vs Bilateral

Variable		Mean	SD	p-value
Canine Inclination	Unilateral	33.3	15.0	.486
	Bilateral	36.2	11.5	
Mx Crowding	Unilateral	-1.2	2.2	.181
	Bilateral	-0.3	2.1	
Md Crowding	Unilateral	-1.2	1.8	.755
	Bilateral	-1.1	1.3	
OJ	Unilateral	3.2	1.0	.351
	Bilateral	2.8	1.5	
OB	Unilateral	3.3	1.5	.159
	Bilateral	4.0	1.6	
Length of Treatment	Unilateral	25.8	7.0	.006*
	Bilateral	32.3	8.5	
Distance from OP	Unilateral	13.9	3.1	.051
	Bilateral	15.6	2.5	
Age	Unilateral	14.6	2.4	.421
	Bilateral	14.0	1.7	

* A p-value of .050 or less is considered statistically significant.

Table 3.8 – Descriptive values for Age vs Distance from the OP and Length of Treatment.

Age (years) #	n	Distance from OP (mm) *	Length of Treatment (months) *
<12	6	16.2	35.2
12-13.9	15	15.9	31.3
14-15.9	17	13.8	25.0
16-17.9	5	13.9	28.4
>18	4	10.5	20.8

OP = Occlusal Plane. * denotes averages for these variables. # Average age at start of treatment.

Figure 3.2 – Boxplot of Length of Treatment vs Distance from the Occlusal Plane for six groupings

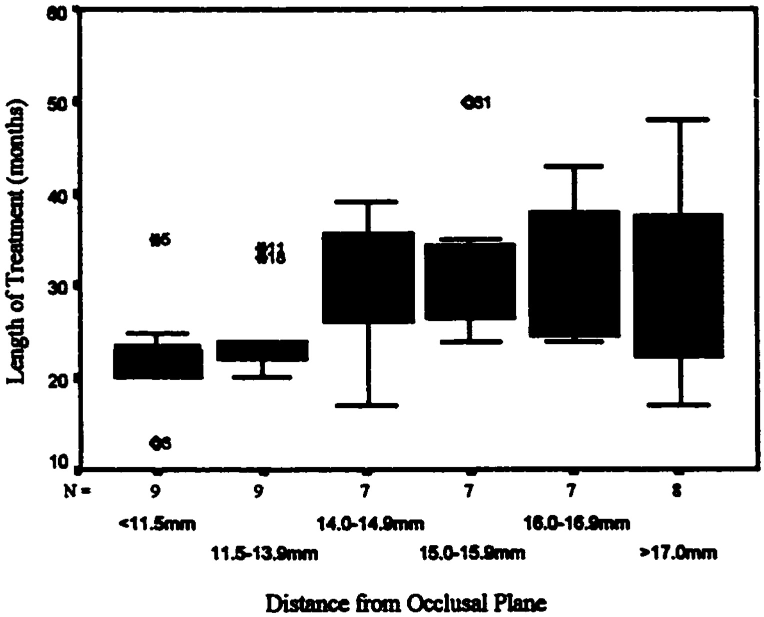


Table 3.9 – Distance from the OP vs Age, CI, Zone and Length of Treatment

Distance from OP (mm)	n	Age (years)#	SD	Canine Inclination (deg)*	SD	Zone*	SD	Length of Treatment (months)*	SD
<11.5	9	16.1	2.3	27.4	12.8	2.8	1.0	22.6	5.8
11.5-13.9	9	14.9	1.6	30.9	10.4	3.4	0.9	25.0	5.0
14.0-14.9	7	14.2	2.9	29.3	13.3	3.3	1.0	30.1	7.7
15.0-15.9	7	14.8	1.4	37.5	9.6	4.5	0.5	33.7	8.8
16.0-16.9	7	13.0	1.9	41.5	13.9	4.0	0.9	30.3	8.0
>17.0	8	13.2	1.2	41.4	17.1	3.4	1.7	30.9	10.2
								p-value = .001	

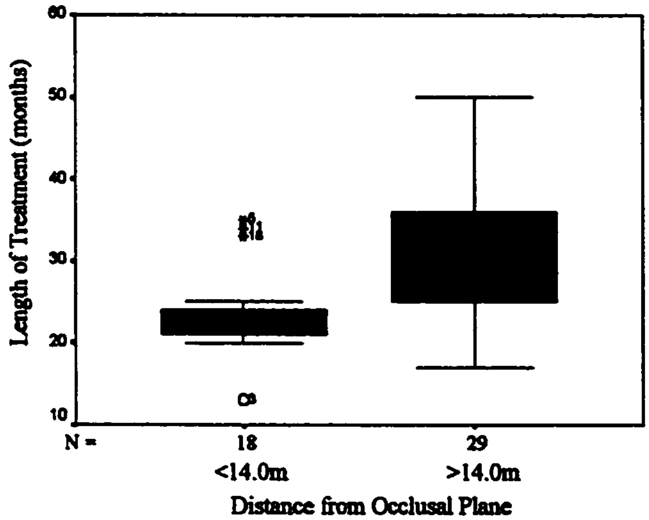
OP = Occlusal Plane. *denotes averages for these variables. # Average age at start of treatment. P-value determined by the Kruskal-Wallis test.

Table 3.10 – Length of Treatment for <14.0mm vs >14.0mm from Occlusal Plane

n	Distance from OP (mm)	Length of Treatment (months)
18	<14.0	23.8
29	>14.0	31.1
p-value		.001*

OP=Occlusal Plane. * A p-value of less than .050 is considered statistically significant. P-value determined by the non-parametric Mann-Whitney test.

Figure 3.3 – Boxplot of Length of Treatment vs Distance from the Occlusal Plane for <14mm vs >14mm



3.7 - References

1. Mead SV. Incidence of impacted teeth. Int J Orthod 1930; 16: 885-90.

2. Dachi SF, Howell FV. A survey of 3874 routine full-mouth radiographs. Oral Surg Oral Med Oral Path 1961; 14: 1165-69.

3. Kramer RM, Williams AC. The incidence of impacted teeth. Oral Surg Oral Med Oral Path 1970; 29: 237-41.

4. Shah RM, Boyd MA, Vakil TF. Studies of permanent tooth anomalies in 7886 Canadian individuals. I: Impacted teeth. J Canad Dent Assoc 1978; 44: 262-64.

5. Grover PS, Lorton L. The incidence of unerupted permanent teeth and related clinical cases. Oral Surg Oral Med Oral Path 1985; 59: 420-25.

6. Ericson S, Kurol J. Radiographic examination of ectopically erupting maxillary canines. Am J Orthod Dentofac Orthop 1987; 91: 483-92.

7. Jacoby H. The etiology of maxillary canine impactions. Am J Orthod 1983; 84: 125-32.

8. Röhrer A. Displaced and impacted canines. Int J Orthod Oral Surg 1929; 15: 1003-20.

9. Hitchin AD. The impacted maxillary canine. Br Dent J 1956; 100: 1-12.

10. Nordenram A, Strömberg C. Positional variations of the impacted upper canine. Oral Surg Oral Med Oral Path 1966; 22: 711-14.

11. Fournier A, Turcotte J-Y, Bernard C. Orthodontic considerations in the treatment of maxillary impacted canines. Am J Orthod 1982; 81: 236-39.

12. Jacoby H. The "ballista spring" system for impacted teeth. Am J Orthod 1979; 75: 143-51.

13. Wolf JE, Mattila K. Localization of impacted maxillary canines by panoramic tomography. Dentomaxillofac Radiol 1979; 8: 85-91.

14. Bishara SE. Clinical management of impacted maxillary canines. Semin Orthod 1998; 4: 87-98.

15. Fink DF, Smith RJ. The duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1992; 102: 45-51.

16. Beckwith RF, Ackerman RJ, Cobb CM, Tira DE. An evaluation of factors affecting duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1999; 115: 439-47.

17. Wisth PJ, Norderval K, Bøe OE. Comparison of two surgical methods in combined surgical-orthodontic correction of impacted maxillary canines. Acta Odont Scand 1976; 34: 53-57.

18. Iramaneerat S, Cunningham SJ, Horrocks E. The effect of two alternative methods of canine exposure upon subsequent duration of orthodontic treatment. Int J Ped Dent 1998; 8: 123-29.

19. Burden DJ, Mullally BH, Robinson SN. Palatally ectopic canines: Closed eruption versus open eruption. Am J Orthod Dentofac Orthop 1999; 115: 634-39.

20. Becker A, Kohavi D, Zilberman Y. Periodontal status following the alignment of palatally impacted canine teeth. Am J Orthod 1983; 84: 332-36.

21. Woloshyn H, Årtun J, Kennedy DB, Joondeph DR. Pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Angle Orthod 1994; 64: 257-64.

22. Pearson MH, Robinson SN, Reed R, Birnie DJ, Zaki GA. Management of palatally impacted canines: the findings of a collaborative study. Eur J Orthod 1997; 19: 511-15.

23. Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. Am J Orthod Dentofac Orthop 1988; 94: 503-13.

24. Stewart JA. Reliability of panoramic reference lines used in describing the position of palatally impacted maxillary canines: a pilot study. (Master's thesis). Edmonton, AB, University of Alberta, 2000.

25. Alger DW. Appointment frequency versus treatment time. Am J Orthod Dentofac Orthop 1988; 94: 436-39.

26. Vig PS, Weintraub JA, Brown C, Kowalski CJ. The duration of orthodontic treatment with and without extractions: a pilot study of five selected practices. Am J Orthod Dentofac Orthop 1990; 97: 45-51.

27. Grewe JM, Hermanson PC. Influence of severity of malocclusion on the duration of orthodontic treatment. Am J Orthod 1973; 63: 533-36.

28. Kuftinec MM, Shapira Y. The impacted maxillary canine: I. Review of concepts. ASDC J Dent Children 1995; 62: 317-24.

29. Fernández E, Bravo LA, Canteras M. Eruption of the maxillary canine quantified in three dimensions. Eur J Orthod 1997; 19: 171-83.

30. Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. Angle Orthod 1994; 64: 249-56.

Chapter Four

Discussion

and

Recommendations

4.1 - General Discussion

Most orthodontic patients are concerned about the length of time that they will be required to wear their fixed appliances. Most of the parents of these patients are concerned about the amount of money orthodontic treatment is going to cost. The orthodontist is concerned about the efficient and successful operation of his office. An accurate estimate of treatment duration for each patient would be a benefit to all three parties. A patient whose treatment is finished "on time" will be a more satisfied patient and may be more likely to speak highly of their treatment and recommend others to the practice. The parents will know their financial responsibility from the beginning and can plan accordingly, and not be surprised near the end of treatment with additional fees. The orthodontist will be able to predict the number of office visits required and will be better able to predict overhead costs for each individual patient. This will allow a fair determination of treatment fees for each patient and result in the successful operation of the orthodontic practice.

Despite the importance of being able to accurately predict orthodontic treatment duration, there have been few studies which have evaluated this or the variables which may affect it. Estimates of the time treatment may take is currently based almost entirely upon subjective clinical experience. Vig et al[1] stated that orthodontic research usually concentrates on the effects of different treatments, and not the efficacy of those treatments.

In an early study, Grewe and Hermanson[2] found no relationship between treatment duration and the severity of the initial malocclusion. Shia[3] noted eighteen factors which he felt increased treatment time in his own practice but he does not provide any data. The top three causes of treatment delays mentioned by Shia were poor patient cooperation, missed appointments, and broken appliances. Alger[4] found that mean treatment duration for his patients was 22 months, with his non-extraction patients taking 4.6 months less than his extraction patients. Vig et al[1] found that five of the nine variables they investigated showed a statistical significance for variation in treatment duration. These five variables included the number of phases involved in treatment, one or both arches treated, age at the start of treatment, pre-treatment molar relation, and whether the case was extraction or non-extraction. However, these five items only explained 33% of the variance in treatment time. Fink and Smith[5] collected data on 118 patients from six different offices and examined a large number of variables they suspected may be involved in duration of treatment. They stated that they could explain 50% of the treatment time variation with a five-step multiple regression equation. The variables in their equation were the number of extracted premolars, number of broken appointments, pretreatment mandibular plane angle, pretreatment ANB angle, and pretreatment Salzmann Index. They also stated that the time spent by individual clinicians in detailed finishing was an important source of unexplained variation in treatment duration.

Beckwith et al[6] noted that Fink and Smith[5] had an error with their statistics and that their equation actually explained only 25% of treatment variation (see page 104). Beckwith et al[6] examined thirty-one variables in their recent study of 140 patients from five orthodontic offices. They found that they could account for 53.6% of the variation in treatment duration using six of the original thirty-one variables. The most important variable in their study explaining differences in treatment time was the number of missed appointments, which accounted for 17.6% of the variance. The other five variables included the number of brackets and bands replaced, the number of treatment phases, poor oral hygiene, the use of headgear, and variation among the five offices. They found that between-office differences accounted for only 6.7% of the treatment time variation. This study explained the highest amount of variation in treatment duration at 53.6%, but this still leaves almost half of the variance in treatment time unexplained. Not evaluated in any of these studies is the quality of the finished result. The time spent on finishing by different clinicians could potentially explain more of the differences in treatment times.

There are very few studies which have looked specifically at the duration of treatment for palatally impacted canines and factors which may influence it. Three studies compared open eruption versus closed eruption methods of exposure of palatally impacted canines and their effect on treatment duration.[7-9] Three other studies stated the duration of treatment as an incidental finding while concentrating their papers on a different aspect of impacted canines.[10-12] This published data shows an average treatment time for these cases to vary from 18 months to 30 months, but individual cases in each study show a large range in treatment duration.

The purpose of this study was to define the pretreatment position of palatally impacted canines, as seen on a panoramic radiograph, and determine if a relationship could be found between these positional variables and the treatment duration of these cases. Currently, an estimate of treatment duration in impacted canine cases is by subjective clinical experience and the actual treatment time can differ widely from this estimate. These variables, specific to palatally impacted canine cases, would be in addition to the common variables discussed in other papers on orthodontic treatment duration.[1-6]

The first part of this study was to verify the reliability of the reference lines used to define the position of the impacted canine as seen on a panoramic radiograph. The vertical reference line, from which the angulation of the impacted canine is determined, was the midline between the axes of the maxillary central incisors. The horizontal reference line, from which the vertical height of the canine is determined, was the occlusal plane line. This line is drawn from the mesio-buccal cusp tip of the maxillary first molar to the incisal edge of the maxillary central incisor on the ipsilateral side of the impacted canine. These reference lines have been commonly used in other publications on the topic of impacted canines[13-15] but no verification of their reliability was found.

Previous research has suggested that vertical measurements in the anterior maxilla from reference lines which are not in the same vertical plane as the anterior maxillary teeth, such as from a line joining the articular eminences or one joining the zygomatic arches, are sensitive to up/down tilting of the skull.[16] Additionally, measurements in the anterior maxilla were found to be more affected by rotation or tilting of the head than measurements in the posterior of the maxilla.[16] Horizontal measurements on panoramic radiographs are not reliable when compared to the actual measurement due to a distortion effect caused by both a projection factor and a motion factor.[17] Carter et al[18] found that small variations in the magnification factor occur with variations in head positioning but this may not be clinically important if the positioning error is small. Angular measurements have shown less variability on panoramic radiographs compared to linear measurements.[17,19,20]

In this pilot study, two vertical, two horizontal, and two angular measurements were made from the reference lines to a metal marker affixed to five adult dry skulls in the approximate location of an impacted canine. Results showed that with 5° rotations of the head in left, right, up and down positions, compared to the ideal position in the panoramic machine, there were statistically significant differences in some of the measurements. In general, the further the linear distance to the point of interest, the more the measurements were statistically significantly different for the different skull rotations. The angle of the vertical marker appeared to be more affected by head movements than the angle of the horizontal marker. This may be due to the vertical part of the marker being in the area of the canine, which has a different magnification factor than the central incisor area where the reference line is located.[18]

However, the variations in the measurements for the different positions were only between 1mm and 3 mm, depending on the measured distance, and less than 3° for the angular measurements, which are probably not clinically significant differences. Ursi et al[19] agree that, for clinical purposes, a 5 degree measurement variation between two exposures is not serious.

These reference lines were determined to be clinically reliable as long as the position of the head in the panoramic machine does not vary by more than 5° from the ideal. With the use of positioning aids, such as light beam markers present on modern panoramic machines, and with proper training, accurate panoramic radiographs should be able to be made on a consistent basis.

The purpose of the second part of this study was to determine whether an accurate prediction of treatment duration could be made from the pretreatment position of a palatally impacted canine as seen on a panoramic radiograph. An additional purpose was to determine if a difference in duration of treatment existed between bilateral and unilateral palatally impacted canine cases.

Impacted canines occur in approximately 1% to 3% of the population[21-26] and are a relatively common anomaly seen in a typical orthodontic practice. A palatal displacement of the maxillary canine will occur 2 to 9 times more often than a labial displacement[26-33] and frequently occurs with few other orthodontic problems. Patients often do not seek treatment until after the age of 12-14 years when the permanent canine is expected to erupt into the arch but does not. Because palatally impacted canine cases oftentimes occur with little else wrong occlusally, they can present a difficult decision for the orthodontist. They are considered to be an important tooth esthetically and functionally but impacted maxillary canine cases are perceived to be more difficult and time consuming than the average orthodontic case. Should one try to bring the impacted tooth into the arch, expecting that this could be a long and difficult treatment, or should one surgically remove the impacted canine and not treat orthodontically if the rest of the occlusion is acceptable as is? An accurate prediction of the time and cost commitment would be beneficial to both orthodontist and patient in making treatment decisions.

A control group, with similar characteristics to the impacted canine group but without an impacted canine, was chosen with which to compare treatment duration. This group had an average treatment time of 22 months. This treatment duration was similar to the results of other studies on duration of treatment.[2,4-6]

The average duration of treatment for the unilateral impacted canine group in this study was 25.8 months, while the treatment time for the bilateral impaction group was 32.3 months. Part of this variation in treatment duration could be attributable to the fact that the most severely impacted canines in the bilateral group were in a slightly significantly worse position than those in the unilateral impacted group. Why this occurred was not explained. The sample size of 18 for the bilateral group was not large and this result could be due to chance, or canines in bilateral cases may be more severely impacted than those in unilateral cases. A bilateral impaction may be a more severe expression of a genetic disorder and is expressed with a more severely impacted tooth. There was a large variation in treatment duration in both impaction groups for individual cases and some of the individual impacted canine cases took less time to treat than individuals in the control group.

Linear regression analysis suggested that the two most important variables which relate to treatment duration in the impacted canine group in this study were 'Age' and 'amount of mandibular crowding.' A linear regression model with 'Age' and 'Md crowding' as the independent variables explained 30% of the variation in treatment time (R^2 = .301). There was a high correlation between the age of the patient and the distance the impacted canine was from the occlusal plane (correlation coefficient = -.520, p-value <.000). The larger the distance the canine was from the occlusal plane, the younger the patient. In agreement with other studies[5] which found that the severity of the initial malocclusion has a relation to treatment duration, the amount of initial mandibular crowding was positively correlated to treatment time in this study.

In an unexpected finding, the younger the patient at the start of treatment the longer the duration of treatment. Those who started orthodontic treatment at 12 years of age or younger required an average of 35 months to complete treatment, while those who were 18 years of age or older only required an average of 20.7 months for treatment completion. Correlation analysis showed that the distance the impacted canine was from the occlusal plane, as measured on the pre-treatment panoramic radiograph, was related to the age of the patient at the start of orthodontic treatment. In the younger ages, the canine was more severely impacted - further from the occlusal plane, at a greater angulation, and more medially displaced. In the older age groups it appeared that the impacted canine had improved its position to a limited extent and was not as severely impacted. Thus, treatment did not take as long to bring the impacted tooth into occlusion.

Another possible explanation for the difference in the severity of impaction of the canine in the different age groups may be the referral pattern of the general dentist. Perhaps the general dentist adopts a 'wait and see' approach with the less severely impacted canines, and if they do not erupt in at a later age, the patient is then referred to the orthodontist. With the more severely impacted canines, the patient may be referred immediately instead of waiting.

The distance from the occlusal plane was also related to the angulation of the canine and its horizontal position, and it was seen that the greater the distance from the occlusal plane, the more angulated and the more medially displaced the impacted canine was found to be. At a distance of <14.0 mm from the occlusal plane, as measured on a panoramic radiograph, average treatment duration was 23.8 months. At a distance >14.0 mm, treatment duration averaged 31.2 months. Why 14.0 mm from the occlusal plane was the dividing line between a shorter treatment time and a longer one was not determined from this study. A panoramic radiograph shows only a two dimensional representation of a three dimensional object, and perhaps the unseen third dimension would add valuable information. With the development of 3-D radiographic techniques just beginning in dental radiography, perhaps we will be better able to represent the true position of an impacted canine in the near future. This may greatly improve our forecasting abilities for the treatment duration of palatally impacted canine cases.

4.2 - Limitations and Suggestions for Future Research

The study verifying the reliability of the reference lines used in the main part of the research was only a pilot study. Thus, the number of subjects is small and should be kept in mind when interpreting the results. A study with a larger number of skulls would be more significant. This larger study could include analysis of different reference lines to determine which would be the most reliable when measuring the position of teeth in different parts of the arch. Another suggestion would be to rotate the skulls by more than 5° to determine at what point the rotations result in radiographs which are no longer clinically acceptable.

Even though 47 subjects, which is often an acceptable sample size, were used in the main part of the study to determine the average treatment time for impacted canine cases, a much larger sample size would be preferred. When some of the variables were further divided into sub-categories, the number of subjects in some of the sub-categories was small. In addition, comparing an impacted canine group to both a non-extraction group and a premolar extraction group would provide more information about treatment duration for different kinds of cases; perhaps it would show a continuum of treatment duration.

Another area of investigation would be to verify the results of this study showing that bilateral impaction cases do indeed take significantly longer to treat than unilateral impactions, and that the most severely impacted canines in these cases is in a worse position than those in unilateral cases. Different variables would need to be studied to determine which of them are important and if there are other reasons that bilateral cases have a significantly longer treatment duration.

A significant portion of the variation in treatment duration in orthodontics remains unexplained by previous studies. The study which explained the most variation in treatment duration still explained only 53.6% of the treatment time.[6] Future investigations which determine variables that explain more of the variation in treatment duration generally, would also help explain more of the variation in impacted canine cases. This would make it easier to more accurately predict the length of time that an individual case will take. This in turn would allow for the more efficient operation of orthodontic offices and allow us to finish more of our orthodontic cases “on time”. Finishing patients “on time” makes for more satisfied patients, which results in more referrals, which ultimately will result in more successful and less stressful orthodontic practices.

4.3 - References

1. Vig PS, Weintraub JA, Brown C, Kowalski CJ. The duration of orthodontic treatment with and without extractions: a pilot study of five selected practices. Am J Orthod Dentofac Orthop 1990; 97: 45-51.

2. Grewe JM, Hermanson PC. Influence of severity of malocclusion on the duration of orthodontic treatment. Am J Orthod 1973; 63: 533-36.

3. Shia GJ. Treatment Overruns. J Clin Orthod 1986; 20: 602-04.

4. Alger DW. Appointment frequency versus treatment time. Am J Orthod Dentofac Orthop 1988; 94: 436-39.

5. Fink DF, Smith RJ. The duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1992; 102: 45-51.

6. Beckwith RF, Ackerman RJ, Cobb CM, Tira DE. An evaluation of factors affecting duration of orthodontic treatment. Am J Orthod Dentofac Orthop 1999; 115: 439-47.

7. Wisth PJ, Norderval K, Bøe OE. Comparison of two surgical methods in combined surgical-orthodontic correction of impacted maxillary canines. Acta Odont Scand 1976; 34: 53-57.

8. Iramaneerat S, Cunningham SJ, Horrocks E. The effect of two alternative methods of canine exposure upon subsequent duration of orthodontic treatment. Int J Ped Dent 1998; 8: 123-29.

9. Burden DJ, Mullally BH, Robinson SN. Palatally ectopic canines: Closed eruption versus open eruption. Am J Orthod Dentofac Orthop 1999; 115: 634-39.

10. Becker A, Kohavi D, Zilberman Y. Periodontal status following the alignment of palatally impacted canine teeth. Am J Orthod 1983; 84:332-36.

11. Woloshyn H, Årtun J, Kennedy DB, Joondeph DR. Pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Angle Orthod 1994; 64: 257-64.

12. Pearson MH, Robinson SN, Reed R, Birnie DJ, Zaki GA. Management of palatally impacted canines: the findings of a collaborative study. Eur J Orthod 1997; 19: 511-15.

13. Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. Am J Orthod Dentofac Orthop 1988; 94: 503-13.

14. Woloshyn H, Årtun J, Kennedy DB, Joondeph DR. Pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Angle Orthod 1994; 64: 257-64.

15. Crescini A, Clauser C, Giorgetti R, Cortellini P, Pini Prato GP. Tunnel traction of infraosseus impacted maxillary canines. A three-year periodontal follow-up. Am J Orthod Dentofac Orthop 1994; 105: 61-72.

16. Xie Q, Soikkonen K, Wolf J, Mattila K, Gong M, Ainamo A. Effect of head positioning in panoramic radiography on vertical measurements: an *in vitro* study. Dentomaxillofac Radiol 1996; 25: 61-66.

17. Larheim TA, Svanaes DB. Reproducibility of rotational panoramic radiography: Mandibular linear dimensions and angles. Am J Orthod Dentofac Orthop 1986; 90: 45-51.

18. Carter LC, Dennison M, Carter JM. Panoramic zonography of the midface: A clinician's guide to vertical magnification. Today's FDA 1990; 2(12): 1C-3C.

19. Ursi WJS, Almeida RR, Tavano O, Henriques JFC. Assessment of mesiodistal axial inclination through panoramic radiography. J Clin Orthod 1990; 24: 166-73.

20. Wyatt DL, Farman AG, Orbell GM, Silveira AM, Scarfe WC. Accuracy of dimensional and angular measurements from panoramic and lateral oblique radiographs. Dentomaxillofac Radiol 1996; 25: 61-66.

21. Mead SV. Incidence of impacted teeth. Int J Orthod 1930; 16: 885-90.

22. Dachi SF, Howell FV. A survey of 3874 routine full-mouth radiographs. Oral Surg Oral Med Oral Path 1961; 14: 1165-69.

23. Kramer RM, Williams AC. The incidence of impacted teeth. Oral Surg Oral Med Oral Path 1970; 29: 237-41.

24. Shah RM, Boyd MA, Vakil TF. Studies of permanent tooth anomalies in 7886 Canadian individuals. I: Impacted teeth. J Canad Dent Assoc 1978; 44: 262-64.

25. Grover PS, Lorton L. The incidence of unerupted permanent teeth and related clinical cases. Oral Surg Oral Med Oral Path 1985; 59: 420-25.

26. Ericson S, Kurol J. Radiographic examination of ectopically erupting maxillary canines. Am J Orthod Dentofac Orthop 1987; 91: 483-92.

27. Jacoby H. The etiology of maxillary canine impactions. Am J Orthod 1983; 84: 125-32.

28. Röhrer A. Displaced and impacted canines. Int J Orthod Oral Surg 1929; 15: 1003-20.

29. Hitchin AD. The impacted maxillary canine. Br Dent J 1956; 100: 1-12.

30. Nordenram A, Strömberg C. Positional variations of the impacted upper canine. Oral Surg Oral Med Oral Path 1966; 22: 711-14.

31. Fournier A, Turcotte J-Y, Bernard C. Orthodontic considerations in the treatment of maxillary impacted canines. Am J Orthod 1982; 81: 236-39.

32. Jacoby H. The "ballista spring" system for impacted teeth. Am J Orthod 1979; 75: 143-51.

33. Wolf JE, Mattila K. Localization of impacted maxillary canines by panoramic tomography. Dentomaxillofac Radiol 1979; 8: 85-91.

Appendix

Inter-office descriptive statistics for the impacted canine group

Office	n	Variable	Minimum	Maximum	Mean	SD
1	13	Age (years)	12.6	19.3	14.3	1.9
		Length of Tx (months)	20.0	50.0	27.7	8.9
		Mx crowding (mm)	-4.0	+6.0	-0.2	2.3
		Md crowding (mm)	-4.0	+3.0	-0.5	1.7
		OJ (mm)	2.0	5.0	3.4	0.8
		OB (mm)	1.0	5.0	3.5	1.2
2	13	Age (years)	10.9	19.5	15.7	2.7
		Length of Tx (months)	13.0	35.0	27.9	6.4
		Mx crowding(mm)	-5.0	+3.0	-1.7	2.0
		Md crowding (mm)	-5.0	0.0	-1.4	1.4
		OJ (mm)	2.0	4.0	2.5	0.7
		OB (mm)	1.0	6.0	3.8	1.7
3	21	Age (years)	10.3	15.7	13.6	1.6
		Length of Tx (months)	17.0	48.0	28.9	8.9
		Mx crowding (mm)	-4.0	+5.0	-0.8	2.2
		Md crowding (mm)	-5.0	0.0	-1.5	1.8
		OJ (mm)	0.0	6.0	3.1	1.6
		OB (mm)	0.0	6.0	3.5	1.7

Inter-office comparisons amongst the three offices

Variable	Df	F	p-value
Age	46	4.301	.020*
Length of Treatment	46	.103	.902
Mx Crowding	46	1.467	.242
Md Crowding	46	1.483	.238
OJ	46	1.820	.174
OB	46	.110	.896

* A p-value of .050 is considered statistically significant.

Impacted Canine Group Demographics

Patient	Sex	Age (months)	Side	Distance from Occlusal Plane (mm)	Canine Inclination (deg)	Zone	Length of Treatment (months)	Angle's Class	Mx Crowding (mm)	Md Crowding (mm)	OJ (mm)	OB (mm)
1	F	124	L	16.6	34	3	43	E-I	-3	-2	5	2
2	F	131	L	14.5	25	4	34	I/I	-4	-2	2	5
3	M	136	L	14.5	36	4	32	I/I	-1	-1	4	5
4	F	136	L	19.5	41	1	40	E-E	-4	-4	4	3
5	F	140	L	16.1	46	5	26	I/I	-2	0	0	0
6	F	142	L	16.2	18	3	36	E-E	-4	-4	4	5
7	F	149	R	19.4	25	3	23	I/I	0	0	2	2
8	M	149	L	18.6	40	3	48	I/I	5	0	6	6
9	F	150	R	15.2	26	4	34	I/I	-2	-2	3	6
10	F	151	R	16.4	45	3	40	E-E	-2	-4	4	1
11	F	152	L	17.2	14	1	31	E-E	-2	0	5	4
12	M	153	L	16.6	57	5	24	R:I / L:E	-4	0	4	4
13	F	153	L	14.9	25	3	25	I/I	0	0	3	3
14	M	156	L	13.9	37	4	33	I/I	0	0	6	6
15	F	159	L	10.1	26	5	25	I/I	0	-1	3	2
16	M	161	R	20.9	41	4	31	I/I	0	0	1	1
17	F	162	L	13.7	34	3	22	I/I	-2	0	4	5
18	M	164	R	16.4	30	4	25	I/I	0	0	3	3
19	M	164	L	15.9	39	5	50	I/I	0	-3	3	5
20	F	164	R	17.1	42	5	35	I/I	0	0	3	3
21	F	167	R	12.7	24	3	23	Sup I	2	-4	3	3
22	M	168	L	13.4	24	3	24	R:I / L:E	0	0	3	5
23	F	168	R	17.7	62	5	17	I/I	0	0	3	4
24	F	168	R	14.9	56	4	37	E-E	-1	-2	2	3
25	M	172	L	11.7	21	5	20	E-E	0	-4	5	6
26	M	173	L	8.9	16	3	23	R:E / L:I	0	0	3	4
27	F	174	R	10.7	10	2	35	I/I	-1	-1	3	2

Impacted Canine Group Demographics (cont)

Patient	Sex	Age (months)	Side	Distance from Occlusal Plane (mm)	Canine Inclination (deg)	Zone	Length of Treatment (months)	Angle's Class	Mx Crowding (mm)	Md Crowding (mm)	OJ (mm)	OB (mm)
28	F	174	R	11.0	48	3	21	I/I	6	3	4	3
29	F	177	R	13.7	39	4	24	I/I	-2	0	2	3
30	M	180	L	15.3	35	4	25	E-E	-3	0	4	5
31	M	181	R	14.8	18	2	17	I/I	-2	-2	3	4
32	F	183	R	10.9	23	2	23	I/I	0	-2	3	4
33	F	183	R	17.4	66	5	22	I/I	0	0	3	4
34	F	186	R	15.5	55	5	30	R:E / L:I	-3	0	2	4
35	M	186	R	11.3	35	3	20	I/I	1	-1	2	2
36	M	186	L	16.0	60	5	24	I/I	0	0	3	3
37	M	187	L	14.4	27	4	39	I/I	0	-2	3	3
38	F	188	R	16.4	42	4	24	I/I	-3	-2	1	3
39	F	192	R	15.5	35	5	35	I/I	-2	-2	3	5
40	M	192	L	15.8	35	4	28	Sup I	3	0	2	6
41	F	199	R	13.2	52	4	22	I/I	1	0	2	3
42	F	200	L	11.8	22	2	34	E-E	-1	-1	3	2
43	F	208	R	13.2	25	3	23	I/I	-1	-1	3	6
44	F	220	L	11.1	43	3	23	I/I	-5	-5	2	5
45	F	231	R	7.0	16	2	20	R:E / L:I	0	0	3	3
46	F	233	L	9.0	30	2	13	R:Sup I / L:I	-2	-2	2	1
47	M	234	R	14.8	18	2	27	I/I	-3	-3	2	2
Average	F-30 M-17	172.5	24-L 23-R	14.5	34.4		28.3	30-Cl I 14-E-E 3-Sup Cl I	-0.9	-1.1	3.0	3.6

Control Group Demographics

Name	Sex	Age (months)	Length of Treatment (months)	Angle's Class	Mx Crowding (mm)	Md Crowding (mm)	OJ (mm)	OB (mm)
1	F	143	32	E/E	-1	0	4	4
2	F	143	31	E/I	0	-1	4	4
3	F	156	17	I/E	-4	-1	2	1
4	M	140	41	Sup I/Sup I	5	-4	5	5
5	M	143	37	I/I	2	-3	5	7
6	F	153	18	I/I	2	0	3	5
7	F	134	22	I/E	0	-1	2	2
8	M	163	14	I/I	0	-6	5	5
9	F	145	12	I/E	-5	-4	4	2
10	M	135	29	I/I	0	-6	5	6
11	F	148	17	I/I	-4	-4	3	5
12	F	134	28	E/E	-5	-1	7	3
13	F	143	34	E/E	5	0	1	1
14	F	159	24	E/I	1	2	3	2
15	F	145	16	E/I	-3	0	4	4
16	F	161	18	I/I	0	0	4	3
17	M	137	24	I/I	0	-2	3	5
18	F	187	10	I/I	2	1	2	0
19	F	152	18	E/E	1	3	1	-1
20	F	151	23	I/I	-5	-4	2	2
21	M	157	26	Sup I/Sup I	0	-5	3	3
22	F	163	17	I/I	-3	-3	2	2
23	M	141	24	E/E	-3	-2	-3	-3
24	F	170	18	I/I	-2	-3	4	3
25	M	157	18	I/I	3	2	2	2
26	F	147	25	I/E	-3	-4	4	6
27	F	161	16	I/I	-2	-2	3	5
28	M	166	24	I/I	4	3	6	5
29	M	144	22	E/I	0	-1	6	4
30	M	180	20	E/I	-2	-1	3	4
31	F	194	24	I/I	3	6	1	1
32	M	177	13	E/I	-6	-1	1	0
33	F	135	15	I/I	-5	-4	2	1
34	F	147	18	I/I	0	5	4	5
35	F	153	21	I/I	1	-4	3	3

Control Group Demographics (cont)

Name	Sex	Age (months)	Length of Treatment (months)	Angle's Class	Mx Crowding (mm)	Md Crowding (mm)	OJ (mm)	OB (mm)
36	F	153	17	I/I	0	-4	4	5
37	M	155	20	I/I	5	4	5	5
38	F	154	34	I/I	2	-1	3	4
39	M	141	16	I/I	-5	-5	3	2
40	M	162	21	I/I	-2	-4	3	4
41	M	151	29	I/I	-3	-4	4	3
42	M	190	24	I/I	-2	-2	2	5
43	M	139	20	I/I	3	1	2	3
44	M	149	30	I/I	3	-1	2	6
45	M	179	25	E/I	3	4	6	6
46	M	158	32	I/I	-4	-4	2	1
47	M	163	18	I/I	1	-1	5	2
Average	F-25 M-22	154.3	22.6	28-Cl I 17-E-E 2-SupI	-0.4	-1.3	3.3	3.2

Reliability Coefficient – Distance from Occlusal Plane

Number of Cases = 25

R = .995 p-value = < .000

Reliability Coefficient – Canine Inclination

Number of Cases = 25

R = .993 p-value = < .000

Intra-rater Reliability – Maxillary Crowding

Number of cases = 10

R = .967 p-value = < .000

Model		95% C. I. For B	
		Lower Bound	Upper Bound
1	(Constant)	- .298	1.028
	MX 2	.744	1.152

Intra-rater Reliability – Mandibular Crowding

Number of Cases = 10

R = .934 p-value = < .000

Model		95% C. I. For B	
		Lower Bound	Upper Bound
1	(Constant)	- .748	.968
	MX 2	.609	1.159

Inter-rater Reliability – Maxillary Crowding

Number of raters - 4 Number of Cases – 5

R = .962 p-value = < .000

Inter-rater Reliability – Mandibular Crowding

Number of raters – 4 Number of Cases – 5

R = .923 p-value = < .000

ANOVA Based on Gender

Variable	F	p-value
Canine Inclination	.126	.724
Mx Crowding	2.379	.130
Md Crowding	.451	.505
OJ	1.823	.184
OB	3.198	.080
Length of Treatment	.198	.744
Distance from OP	.453	.504
Age	.014	.908

Descriptive Statistics – Unilateral vs Bilateral

	Variables	n	Minimum	Maximum	Mean	S.D.
Unilateral	C. I. (deg)	29	10.0	66.0	33.3	15.0
	Distance from OP (mm)		7.0	19.5	13.9	3.1
	Age (years)		10.0	19.5	14.6	2.4
	Length of Tx (months)		13.0	40.0	25.8	7.0
	Mx Crowding (mm)		-5.0	6.0	-1.2	2.2
	Md Crowding (mm)		-5.0	3.0	-1.2	1.8
	OJ (mm)		2.0	6.0	3.2	1.0
	OB (mm)		1.0	6.0	3.3	1.5
Bilateral	C. I. (deg)	18	18.0	56.0	36.2	11.5
	Distance from OP (mm)		9.8	19.0	15.6	2.5
	Age (years)		10.3	16.7	14.0	1.7
	Length of Tx (months)		23.0	50.0	32.3	8.5
	Mx Crowding (mm)		-3.0	5.0	-0.3	2.1
	Md Crowding (mm)		-4.0	0.0	-1.1	1.3
	OJ (mm)		0.0	6.0	2.8	1.5
	OB (mm)		0.0	6.0	4.0	1.6

CI = Canine Inclination. OP = Occlusal Plane.

Descriptive Statistics – Length of Treatment as variable of interest

Length (months)	Variables	n	Minimum	Maximum	Mean	S.D.
<20	C. I. (deg)	3	18.0	62.0	36.7	22.7
	Distance from OP (mm)		9.0	17.7	13.9	4.4
	Age (years)		14.0	19.4	16.2	2.9
	Mx Crowding (mm)		-2.0	0.0	-1.3	1.2
	Md Crowding (mm)		-2.0	0.0	-1.3	1.2
	OJ (mm)		2.0	3.0	2.7	0.6
	OB (mm)		1.0	4.0	3.0	1.7
20-24	C. I. (deg)	18	16.0	66.0	36.1	15.6
	Distance from OP (mm)		7.0	19.4	13.2	3.1
	Age (years)		12.4	19.3	15.2	1.8
	Mx Crowding (mm)		-5.0	6.0	-0.4	2.4
	Md Crowding (mm)		-5.0	3.0	-0.9	1.9
	OJ (mm)		1.0	5.0	2.9	0.9
	OB (mm)		2.0	6.0	3.8	1.2
25-29	C. I. (deg)	7	18.0	46.0	30.7	9.0
	Distance from OP (mm)		10.1	16.4	14.8	2.1
	Age (years)		11.7	19.5	14.6	2.6
	Mx Crowding (mm)		-3.0	3.0	-0.7	2.1
	Md Crowding (mm)		-3.0	0.0	-0.6	1.1
	OJ (mm)		0.0	4.0	2.4	1.3
	OB (mm)		0.0	6.0	3.0	2.0
30-35	C. I. (deg)	11	10.0	55.0	31.2	13.2
	Distance from OP (mm)		10.7	20.9	15.2	2.7
	Age (years)		10.9	16.7	13.7	1.9
	Mx Crowding (mm)		-4.0	0.0	-1.5	1.3
	Md Crowding (mm)		-2.0	0.0	-0.8	0.9
	OJ (mm)		1.0	6.0	3.2	1.4
	OB (mm)		1.0	6.0	3.9	1.7
>35	C. I. (deg)	8	18.0	56.0	37.5	11.5
	Distance from OP (mm)		14.4	19.6	16.6	1.7
	Age (years)		10.3	15.6	12.7	1.7
	Mx Crowding (mm)		-4.0	5.0	-1.1	2.9
	Md Crowding (mm)		-4.0	0.0	-2.6	1.4
	OJ (mm)		2.0	6.0	3.9	1.2
	OB (mm)		1.0	6.0	3.5	1.7

CI = Canine Inclination. OP = Occlusal Plane.

Descriptive Statistics – Age as variable of interest

Age (Years)	Variables	n	Minimum	Maximum	Mean	S.D.
10-11.9	C.I. (deg)	6	18.0	46.0	33.3	10.3
	Mx Crowding (mm)		-4.0	-1.0	-3.0	1.3
	Md Crowding (mm)		-4.0	0.0	-2.2	1.6
	OJ (mm)		0.0	5.0	3.2	1.8
	OB (mm)		0.0	5.0	3.3	2.1
	Length of Tx (months)		26.0	43.0	35.2	6.0
	Distance from OP (mm)		14.5	19.5	16.2	1.9
12-13.9	C.I. (deg)	15	14.0	57.0	33.7	10.8
	Mx Crowding (mm)		-4.0	5.0	-0.3	2.1
	Md Crowding (mm)		-4.0	0.0	-0.9	1.5
	OJ (mm)		1.0	6.0	3.5	1.4
	OB (mm)		1.0	6.0	3.6	1.7
	Length of Tx (months)		22.0	50.0	31.3	9.0
	Distance from OP (mm)		10.1	20.9	15.9	2.7
14-15.9	C.I. (deg)	17	10.0	66.0	37.5	17.8
	Mx Crowding (mm)		-3.0	6.0	-0.5	2.1
	Md Crowding (mm)		-4.0	3.0	-0.8	1.5
	OJ (mm)		1.0	5.0	2.8	0.9
	OB (mm)		2.0	6.0	3.6	1.1
	Length of Tx (months)		17.0	39.0	25.0	6.5
	Distance from OP (mm)		8.9	17.7	13.8	2.6
16-17.9	C.I. (deg)	5	22.0	52.0	33.8	11.7
	Mx Crowding (mm)		-2.0	3.0	0.0	2.0
	Md Crowding (mm)		-2.0	0.0	-0.8	0.8
	OJ (mm)		2.0	3.0	2.6	0.5
	OB (mm)		2.0	6.0	4.4	1.8
	Length of Tx (months)		22.0	35.0	28.4	6.0
	Distance from OP (mm)		11.8	15.8	13.9	1.7
>18	C.I. (deg)	4	16.0	43.0	26.8	12.5
	Mx Crowding (mm)		-5.0	0.0	-2.5	2.1
	Md Crowding (mm)		-5.0	0.0	-2.5	2.1
	OJ (mm)		2.0	3.0	2.3	0.5
	OB (mm)		1.0	5.0	2.8	1.7
	Length of Tx (months)		13.0	27.0	20.8	5.9
	Distance from OP (mm)		7.0	14.8	10.5	3.3

CI = Canine Inclination. OP = Occlusal Plane.

Descriptive Statistics – Distance from Occlusal Plane as variable of interest

Distance from OP (mm)	Variables	n	Minimum	Maximum	Mean	S.D.
< 11.5	C.I. (deg)	9	10.0	48.0	27.4	12.8
	Age (years)		13.3	19.4	16.0	2.3
	Mx Crowding (mm)		-5.0	6.0	-0.1	2.9
	Md Crowding (mm)		-5.0	3.0	-1.0	2.1
	OJ (mm)		2.0	3.0	2.8	0.7
	OB (mm)		1.0	6.0	4.1	1.6
	Length of Tx (months)		13.0	35.0	22.6	5.8
11.5-13.9	C.I. (deg)	9	21.0	52.0	30.9	10.4
	Age (years)		13.0	17.3	14.9	1.6
	Mx Crowding (mm)		-2.0	2.0	-0.3	1.3
	Md Crowding (mm)		-4.0	0.0	-1.1	1.7
	OJ (mm)		2.0	6.0	3.4	1.3
	OB (mm)		0.0	6.0	2.7	1.7
	Length of Tx (months)		20.0	34.0	25.0	5.0
14.0-15.9	C.I. (deg)	7	18.0	56.0	29.3	13.3
	Age (years)		10.9	19.5	14.2	2.9
	Mx Crowding (mm)		-4.0	0.0	-1.6	1.5
	Md Crowding (mm)		-3.0	0.0	-1.7	1.0
	OJ (mm)		2.0	4.0	2.7	0.8
	OB (mm)		2.0	6.0	4.0	1.5
	Length of Tx (months)		17.0	39.0	30.1	7.7
15.0-15.9	C.I. (deg)	7	26.0	60.0	40.7	12.2
	Age (years)		12.5	16.0	14.9	1.3
	Mx Crowding (mm)		-3.0	3.0	-1.0	2.2
	Md Crowding (mm)		-3.0	0.0	-1.0	1.3
	OJ (mm)		2.0	4.0	2.9	0.7
	OB (mm)		3.0	5.0	3.7	1.0
	Length of Tx (months)		24.0	50.0	32.3	8.8
16.0-16.9	C.I. (deg)	7	18.0	57.0	38.9	12.7
	Age (years)		10.3	15.7	12.6	1.7
	Mx Crowding (mm)		-4.0	0.0	-2.6	1.4
	Md Crowding (mm)		-4.0	0.0	-1.7	1.8
	OJ (mm)		0.0	5.0	3.0	1.8
	OB (mm)		1.0	5.0	3.0	1.7
	Length of Tx (months)		24.0	43.0	31.1	8.3
>17.0	C.I. (deg)	8	14.0	66.0	41.4	17.1
	Age (years)		11.3	15.3	13.2	1.2
	Mx Crowding (mm)		-4.0	5.0	-0.1	2.5
	Md Crowding (mm)		-4.0	0.0	-0.5	1.4
	OJ (mm)		1.0	6.0	3.4	1.6
	OB (mm)		2.0	6.0	4.1	1.4
	Length of Tx (months)		17.0	48.0	30.9	10.2

CI = Canine Inclination. OP = Occlusal Plane.

Regression Analysis – Model Summary[13]

Model	R	R^2	Adjusted R^2	p-value
1	.691	.477	.248	.042
2	.690	.476	.270	.026
3	.688	.473	.288	.016
4	.686	.471	.304	.009
5	.683	.466	.318	.006
6	.679	.461	.330	.003
7	.676	.457	.342	.002
8	.671	.450	.352	.001
9	.656	.431	.345	.001
10	.640	.410	.338	.000
11	.608	.370	.310	.001
12	.589	.347	.301	.000
13	.549	.301	.269	.000

1. Predictors: Zone4, Mx, Age, Inclination, OB, 1-molar 1; 0-otherwise, 1-male 0-female, 1-zone 1; 0-otherwise, 1-molar 0; 0-others, Zone3, Md, Distance, OJ, Zone2
2. Predictors: Zone4, Mx, Age, Inclination, OB, 1-molar 1; 0-otherwise, 1-male 0-female, 1-zone 1; 0-otherwise, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
3. Predictors: Zone4, Mx, Age, Inclination, OB, 1-molar 1; 0-otherwise, 1-male 0-female, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
4. Predictors: Zone4, Mx, Age, Inclination, 1-molar 1; 0-otherwise, 1-male 0-female, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
5. Predictors: Zone4, Mx, Age, 1-molar 1; 0-otherwise, 1-male 0-female, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
6. Predictors: Zone4, Mx, Age, 1-male 0-female, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
7. Predictors: Zone4, Mx, Age, 1-molar 0; 0-others, Zone3, Md, Distance, OJ
8. Predictors: Zone4, Mx, Age, 1-molar 0; 0-others, Md, Distance, OJ
9. Predictors: Mx, Age, 1-molar 0; 0-others, Md, Distance, OJ
10. Predictors: Mx, Age, 1-molar 0; 0-others, Md, Distance
11. Predictors: Mx, Age, Md, Distance
12. Predictors: Age, Md, Distance
13. Predictors: Age, Md
14. Dependent Variable: Length