The Effect of the Dental Follicle Volume of Palatally Impacted Maxillary Canines on the Relative Position of the Adjacent Teeth

by

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Abstract

Introduction: Cone-Beam Computed Tomography (CBCT) has provided in-depth three-dimensional insight into the field of dentistry that were not readily available in the past. It is typically used as an adjunct with traditional imaging modalities to use as a diagnostic aid in orthodontics where uncertainty exists such as planning and treating impacted dentition. The primary objective of this study is to assess how the volume of the dental follicle of palatally impacted maxillary canines affects the relative position (in terms of tip, torque, and rotation) of the adjacent lateral incisor and first premolar using CBCT imaging.

Methods: The sample consists of 49 patients with unilaterally palatally impacted maxillary canines with dental follicles who had CBCT imaging taken. These 49 patients were further assigned to a lateral incisor sample (n = 49) and first premolar sample (n = 23) dependent on the direct contact of the dental follicle to that adjacent tooth. Using CBCT imaging software (OsiriX DICOM Viewer), a manual human segmentation technique was used to obtain the volumetric measurements of the dental follicle of the impacted maxillary canine and angular measurements of the adjacent lateral incisor and first premolar were obtained by using the palatal plane (ANS – PNS) as a reference plane. The angles were then compared to the contralateral non-impacted side which acted as the control. Intraclass coefficient was used to measure the reliability of the principal investigator's angular and volumetric measurements as well as the reliability of the volumetric measurements amongst the three participating investigators. A multivariant regression analysis was used. Data analysis was performed using IBM SPSS Software and statistical significance was set at α=0.05.

Results: Intra-rater reliability for the first premolar tip and torque angular measurements were good, as the Intra-Class Correlation (ICC) was measured at 0.896 (0.796, 0.954) and 0.861 (0.734, 0.937), respectively. Intra-rater reliability was excellent for the dental follicle volume, lateral incisor tip, torque and rotation, and first premolar rotation, as the ICC was measured at 0.979 [0.940,0.994], 0.921 [0.844, 0.965], 0.971 [0.941, 0.988], 0.995 [0.989, 0.998], and 0.936 [0.871, 0.972] respectively. Inter-rater reliability was good for the dental follicle volume amongst the three investigators, as the ICC was measured at 0.876 [0.707, 0.973]. The multivariant regression analysis implied that there is no difference in the mean change in the tip, torque, and rotation of the lateral incisor and first premolar between the impacted and control sides when dental follicle volumes are considered ($p = 0.509$ for the lateral incisor sample and $p = 0.804$ for the first premolar sample).

Conclusion: The dental follicle volume of the palatally impacted maxillary canine does not seem to influence the relative position of the adjacent lateral incisor and first premolar. There was no statistically significant difference between the change in angular tip, torque, and rotation of the adjacent teeth between the impacted and control maxillary canine sides.

Preface

This thesis is an original work by Dr. Michael Lam. This research project, of which this thesis a part, received ethics approval from the University of Alberta Ethics Board under the ID: Pro00087314 on October 15, 2021. Samples were also obtained from the Universita degli Sutdi della Campania Luigi Vanvitelli - Diparmento Multidisciplinare di Specialità Medico-Chirurgiche e Odontoiatriche (Italy), the Hebrew University-Hadassah School of Dental Medicine (Israel) and the University of Gothenburg – Sahlgrenska Academy – Department of Orthodontics (Sweden) where the appropriate ethics were obtained and approved at those institutions. No part of this thesis has been previously published.

Dr. Carlos Flores-Mir, Dr. Stella Chaushu and Dr. Camila Pacheco-Pereira assisted in the concept formation, as well as the revision of the written work. Dr. Ludovica Nucci (Italy), Dr. Eyal Dekel (Israel) and Dr. Julia Naoumova (Sweden) assisted with providing additional samples for this thesis. Dr. Davin Truong assisted as the second reviewer in Chapter 2. Dr. Ludovica Nucci (Italy) and Dr. Eyal Dekel (Israel) assisted with the inter-rater reliability readings in Chapter 4.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

Nomenclature

Abbreviations

SLOB	Same Lingual Opposite Buccal
CBCT	Cone-Beam Computed Tomography
3D	Three-dimensional
DICOM	Digital Imaging and Communications in Medicine
H_0	Null Hypothesis
H_a	Alternate Hypothesis
ScR	Scoping Review
ROI	Region of Interest
ANS	Anterior Nasal Spine
PNS	Posterior Nasal Spine
ICC	Intraclass Correlation Coefficient

Chapter 1

Introduction

1.1 Review of Maxillary Impacted Cuspids

1.1.1 Brief Overview and Etiology of Maxillary Impacted Cuspids

The maxillary cuspids, commonly referred to as canines, act as the cornerstones of the upper dental arch, providing the esthetics to create a harmonious smile and ideal function to ensure canine guidance during excursive jaw movements protecting the posterior dentition. The position of the cuspids is of great importance in orthodontics. The goal is for the mesial incline of the maxillary canine to occlude anteriorly with the distal incline of the mandibular canine, also referred to as an Angle's Class I relationship (shown in *Figure 1.1*).

Figure 1.1 – Photo of the ideal cuspid position of an Angle's Class I occlusion

In the average individual, the maxillary canines generally erupt around 11.5 years.[1] When a tooth fails to erupt into the oral cavity and deviates from the normal eruption pattern and timing, it is commonly referred to as tooth impaction (shown in *Figure 1.2*). The maxillary cuspids are the most frequently impacted teeth following the maxillary/mandibular third molars, occurring in approximately 0.92 – 2.2% of the population and are more commonly seen in females two to three times as much as males.[2-4]

Figure 1.2 – A traditional orthopantomogram (panoramic) radiograph illustrating palatal impaction of tooth #23

The etiology of maxillary impacted canines is still a debated topic to this day. Considering other contributing factors such as local obstruction and/or pathology, two main theories describe the etiopathogenesis of maxillary impacted canines.

The first theory revolves around the idea that the maxillary canine eruption path is influenced by the morphology and presence of the adjacent lateral incisor, essentially guiding the maxillary canine along the distal aspect of the tooth into its position as it erupts into the dental arch. If the lateral incisor is absent, late developing, peg-shaped or small with delayed root development, the canine may not erupt along the proper path into the dental arch. This is known as the "guidance theory".

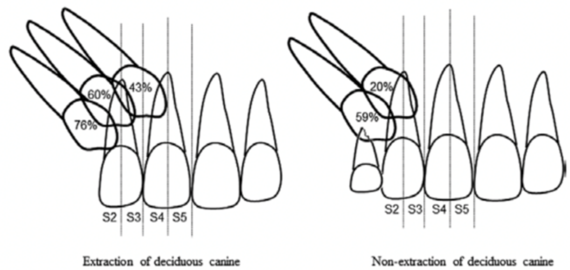
The second theory revolves around the idea that maxillary impacted canines have an increased prevalence within the families of affected patients, and there is an association with other genetic anomalies within the same dentition such as congenitally missing lateral incisors and second premolars, peg laterals and enamel hypoplasia. This is known as the "genetic theory".[4]

Maxillary impacted canines are more often palatally displaced than buccally displaced canines at a 6:1 ratio and typically present as unilateral impactions, as 17-45% of palatally impacted maxillary canines cases present as bilateral impactions.[5,6] Buccally displaced canines are thought to be a result of an arch length deficiency due to crowding where there may have been early loss of the deciduous canine and subsequent space loss where the tooth used to occupy, or the jaw is unable to accommodate the widths of the erupting permanent teeth. While palatally displaced canines have been associated with the guidance theory and genetic theory mentioned previously.[3,7,8]

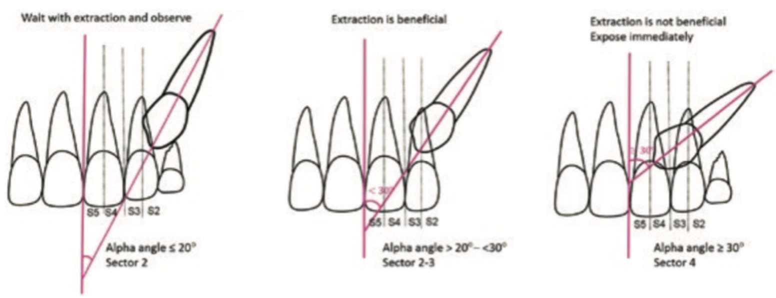
Treatment of maxillary impacted canines includes observation, extraction of the deciduous canine to attempt spontaneous correction – extraction socket would be the path of less resistance, surgical exposure with or without orthodontic treatment, autotransplantation or extraction of the impacted canine. Failure to identify and treat impacted maxillary canines can lead to many undesirable outcomes, including displacement, and resorption of the neighboring teeth, canine ankylosis and resorption, dentigerous cyst formation, and recurrent infections. Subsequently, this could potentially compromise tooth vitality and supporting structures such as the periodontium and alveolar bone.[9,10]

1.1.2 Classification and Degree of Impaction of Maxillary Cuspids

Over the years, several classification systems have been created to describe the position of the palatally impacted canine and to act as a guide for dental professionals to determine the most predictable treatment. In the classic study by Ericson and Kurol (1988), they researched the early intervention of extracting primary canines and determined the success rate of such treatment based on a classification system that identified the position of the impacted canine relative to the ipsilateral maxillary incisors.[11] The severity of impaction was determined by sectors that identified the horizontal and vertical position of the impacted canine in relation to the adjacent dentition and the inclination of the impacted canine relative to the midline, referred to as the *alpha angle*. This was further elaborated upon by Naoumova and Kjellberg (2018) as shown in *Figure 1.3*.[12]



(a) Illustration of the percentage of the spontaneous eruption of the palatally impacted Maxillary canine based on the sector position (denoted by S) of the impacted tooth relative to the incisors and extraction of the deciduous canine



(b) Illustration of the alpha angle of palatally impacted maxillary canine and the cut-off when interventional extraction of the canine is beneficial.

Figure 1.3 – Schematic drawings of the sector and alpha angle of palatally impacted maxillary canines and the success of spontaneous eruption based on deciduous canine extraction. Figures 3 and 4 from Naoumova et al.[12]

1.1.3 Dental Radiography of Impacted Maxillary Cuspids

Traditionally, the radiographic views commonly used for assessing impacted canines included periapical (with the SLOB rule), maxillary occlusal, and panoramic radiographs. With the ongoing technological advancement in dentistry, Cone Beam Computed Tomography (CBCT) has provided a three-dimensional (3D) insight into impacted canines, especially in cases of root resorption, and eliminated the problems with superimposition and magnification that were seen in conventional radiography (as shown in *Figure 1.4*).[12] Although, CBCT ionizing radiation dosage is higher than 2D imaging modalities, the use of newer machines, proper imaging parameters and patient protective equipment has been able to reduce the overall CBCT ionizing radiation dosage. Studies comparing CBCT and panoramic radiographs showed differences in favor of CBCT when looking at labio-palatal cusp position, mesiodistal apex position and adjacent teeth resorption. Subsequently, there have been mixed results on whether there is a significant influence on the overall treatment plan when using the various radiographic methods, which brings to question whether routine CBCT is warranted in treating most of these cases.[13,14]

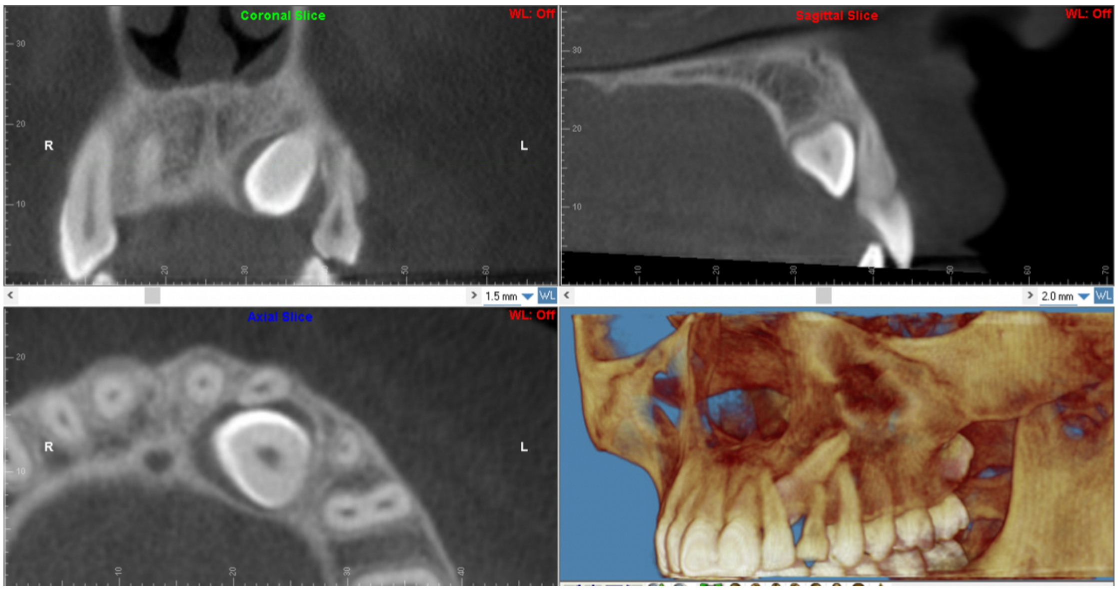


Figure 1.4 – A 3D cone beam computed tomography (CBCT) radiograph illustrating palatal impaction of tooth #23 on Dolphin Imaging Software

With the gaining popularity of CBCT 3D imaging and advancements of these imaging techniques in dentistry focusing on hard tissue structures such as the dentition, there has been an abundance of information that was not previously accessible with traditional 2D imaging techniques. An example of this is volumetric measurements of desirable structures. To do so, one must isolate the structure of interest from its surroundings in a process referred to as segmentation. However, there has been a lack of homogeneity of what volumetric measurement protocol to be used and determined to be the gold standard. Three protocols are generally used for segmentation and are as follows:

- Manual human segmentation
- Automated segmentation with human refinement (semi-automatic)
- Automated segmentation without human refinement (automatic)

Manual human segmentation involves the user to identify the structure of interest (in this case, the dental follicle) on a 2D slice-by-slice basis from the CBCT and to highlight the individual voxel of interest to create a region of interest for the segmentation. This can be incredibly time consuming when compared to the other two methods. Automatic segmentation involves the use of a "seed voxel" of the desired structure which the CBCT imaging software then selects the largest connected area that contains the voxel itself and all voxels with gray values contained within a specified range. This is a much more efficient method compared the manual human segmentation. The semi-automatic segmentation is a combination of the two previously mentioned methods where the automatic segmentation is implemented and then refined by manual segmentation to correct any areas that may have unnecessarily captured by the seed voxel. When comparing the three different methods, the semi-automatic segmentation (with manual refinement) had shown the best intra-observer (ICC = 0.996) and inter-observer (ICC = 0.990) reliability when segmenting the maxillary first molar tooth.[15-17]

1.1.4 Maxillary Impacted Canines Affecting Adjacent Teeth Position

Only a few studies assessed the effects of the maxillary impacted canines and the relative position of the adjacent lateral incisors and first premolar based on CBCT imaging. According to a recent retrospective observational study by Dekel et al. (2021) that assessed 34 unilateral maxillary buccally and palatally impacted canines in patients with a mean age of 16.5 years, it was concluded that there are pathognomonic differences in the labio-palatal position of the impacted canine and the rotation, angulation, and torque of the adjacent lateral incisor and first premolar.[7] Therefore, they may be used as early clinical signs for recognizing and differentiating incipient canine displacements. For example, if a lateral incisor is mesiolabially rotated, has a mesial root angulation, and a buccally displaced root (or palatally displaced crown), a palatal canine displacement can be suspected. In contrast, a mesiolabially rotated lateral incisor with a normally angulated but significantly palatally displaced root should indicate a potential buccal canine displacement. In addition, when considering the first premolar, a mesiobuccal rotation and a slightly buccally displaced root would lead the clinician to suspect a palatally impacted canine.[7] The findings in this study were similar to another CBCT study by Liuk et al.[18] that focused on maxillary lateral incisor position in association with palatally impacted maxillary canines. They found a similar retroclination and mesiolabial rotation of the maxillary lateral incisor; however, they differed in the root angulation, which they found to be more upright.[18]

1.2 Review of Dental Follicles

The dental follicle comprises a fluid-filled, loose connective tissue sac surrounding the crown of the developing tooth, acting as a source of osteoblasts, cementoblasts and fibroblasts that aid in forming the periodontium surrounding the dentition. It also initiates the resorptive process of the deciduous tooth root and surrounding bone, which creates the eruption path for the underlying permanent dentition.[11] An example of the dental follicle viewed on a CBCT image can be seen in *Figure 1.5* (viewed and traced on OsiriX DICOM Viewer Version 13.01). With the use of CBCT imaging, Ericson and Bjerklin (2001) determined, with a 95% confidence interval, that the width of dental follicle was 2.3-2.7 mm for a normally erupting maxillary canine and 2.7-3.2 mm for an ectopically erupting maxillary canine based on the largest distance from the crown of the maxillary canine to the periphery of the follicle from the axial view.[19] Anything greater than these widths, noted as an enlargement of the follicular sac dimensions, could be considered hyperplastic or pathologic in nature; however, it can be difficult to differentiate between the two – there is an overlap between the upper bound and lower bound of the two groups and that a difference of 0.1-0.5 mm may be just a measurement error. If pathologic changes were to occur, it would most likely occur in the second decade of life and is most frequently a dentigerous cyst, an entity formed by the hydrostatic force exerted by accumulation of fluid between the reduced enamel epithelium and a tooth crown. In the same study, they also found that the width of the dental follicle was greater in labially displaced canines than in normally erupting or palatally displaced canines due to the cortical bone thickness and roots of the adjacent teeth.[19] The previous areas of dental follicular investigation concerning impacted canines primarily focused on root resorption of the adjacent incisors utilizing computed tomography imaging. It was seen that the follicle of the canine does not cause root resorption of the adjacent incisors but is most likely a result of the physical contact of the canine and the incisor, as well as the eruption process of the canine. This was believed to be the reason for the deviation of the adjacent root positions but was not confirmed by the study mentioned above.[13,14,19]

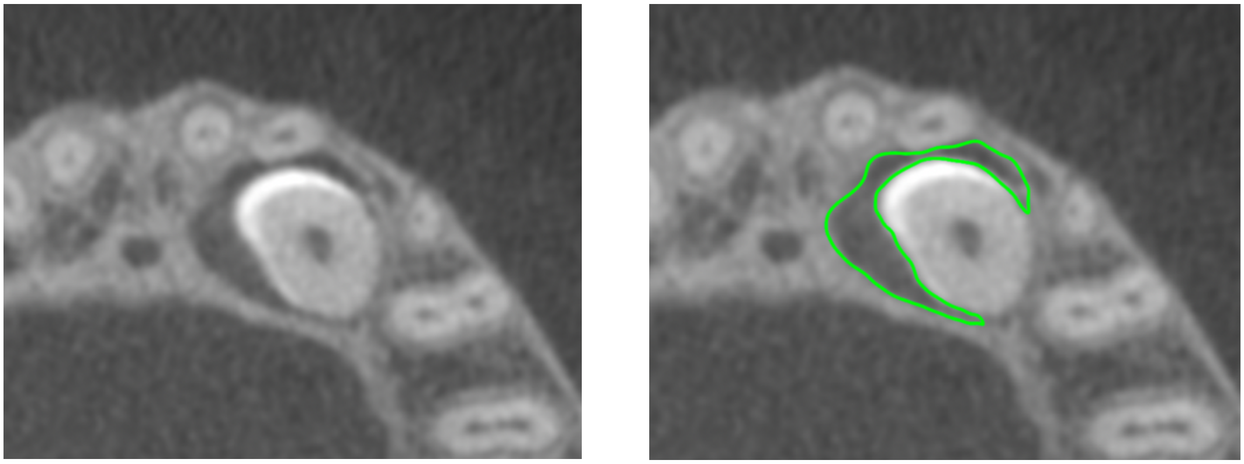


Figure 1.5 – CBCT imaging of palatally impacted tooth #23 illustrates the dental follicle surrounding the tooth's crown, as highlighted in green.

1.3 Purpose and Objectives

To date, no studies have focused on the relationship between the dental follicle of palatally impacted maxillary canines and the effect on the position of the adjacent teeth. There also have been no studies that have focused on the volumetric measurement of the dental follicle of maxillary canines as they have traditionally been based on a linear measurement in millimetres from the crown of the canine to the periphery of the dental follicle, whether it is 2D imaging or CBCT. With the compressive forces created by the dental follicle during tooth eruption, which could subsequently displace the adjacent teeth, this is a unique perspective on the potential effects of the impacted maxillary canine and its associated dental follicle. This could warrant early intervention to manage dental follicles to avoid certain malocclusion traits.

The primary research purpose of this study is to assess how the volume of the dental follicle of palatally impacted maxillary canines affects the relative position (in terms of tip, torque, and rotation) of the adjacent lateral incisor and first premolar. The volume of the dental follicle and the relative position of the adjacent teeth will be assessed with pre-treatment CBCT imaging. This research study will further elaborate upon and adapt to the methodology developed by Dekel et al. (2021) for measuring the tip, torque, and rotation of the lateral incisor and first premolar.[7]

1.3.1 Research Question

This thesis aims to address the following question:

- How does the volume of the dental follicle of palatally impacted maxillary canines affect the relative position (tip, torque, and rotation) of the adjacent lateral incisor and first premolar?

1.3.2 Hypothesis

The following null hypothesises, and alternative hypothesises are proposed for the research question:

- H_0 = there is no difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the lateral incisor between the impacted and control sides when comparing the volume of the dental follicle as it contacts the lateral incisor.
- H_a = there is a difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the lateral incisor between the impacted and control sides when comparing the volume of the dental follicle as it contacts the lateral incisor.
- H_0 = there is no difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the first premolar between the impacted and control sides when comparing the volume of the dental follicle as it contacts the first premolar.
- H_a = there is a difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the first premolar between the impacted and control sides when comparing the volume of the dental follicle as it contacts the first premolar.

Chapter 2

Scoping Review

2.1 Introduction

Tooth impaction refers to the inability of the tooth to erupt into the oral cavity after its normal dental developmental pattern is complete. This is generally due to an arch length and tooth width discrepancy creating a lack of space for the permanent tooth to erupt correctly, also called dental crowding. The prevalence of impacted maxillary canines has been reported between 0.92% – 2.2% of patients.[2-4,20]

For impacted canines, in addition to dental crowding, other theories believe that the adjacent lateral incisor tooth morphology (known as the "guidance theory") and particular hereditary factors, the "genetic theory", play a role in the impaction of the maxillary canines. Failure to identify and treat impacted upper canines can lead to many undesirable outcomes, including displacement and/or resorption of the neighboring teeth, canine ankylosis and resorption, and recurrent infections. Subsequently, this could potentially compromise tooth vitality and supporting structures such as the periodontium and alveolar bone.[21]

Only a few studies have been done to assess the effects of the maxillary impacted canines and the relative position of the adjacent lateral incisors and first premolar based on Cone-Beam Computer Tomography (CBCT) imaging. A recent retrospective observational study by Dekel et al. (2021) that assessed 34 unilateral maxillary buccally and palatally impacted canines in patients with a mean age of 16.5 years.[7] The study concluded that there are pathognomonic differences in the labio-palatal position of the impacted canine and the rotation, angulation, and torque of the adjacent lateral incisor and first premolar. Therefore, they may be used as early clinical signs for recognizing and differentiating incipient canine displacements. This study focused on the severity of the impaction of the maxillary canine and the association between the impaction severity and the canine root development in conjunction with the adjacent tooth positions.[7] No attempt was made to assess any potential association between the dental follicle volume of the impacted canine on the amount of displacement.

When permanent teeth fail to erupt, it is seen that the dental follicle (also referred to as dental sac) of the developing tooth may remain attached to the crown, inserting itself at the cementoenamel junction, and may remain for life.[22] The dental follicle comprises a vascular fibrous, loose connective tissue sac surrounding the crown of the erupting tooth, acting as a source of osteoblasts, cementoblasts and fibroblasts that aid in forming the periodontium surrounding the dentition. It also initiates the resorptive process of the deciduous tooth root and surrounding bone, which creates the eruption path for the underlying permanent dentition.[11] This unique structure can be visualized on various radiographic imaging modalities used in the dental field today, such as panoramic radiographs and CBCT.

With the use of CBCT imaging, it was determined that the width of dental follicle was 2.3-2.7 mm for a normally erupting maxillary canine and 2.7-3.2 mm for an ectopically erupting maxillary canine (with a 95% confidence interval) based on the largest distance from the crown of the maxillary canine to the periphery of the follicle from the axial view. Larger follicular widths (at least 3-4 mm in width) could be considered hyperplastic or pathologic in nature; however, it can be challenging to differentiate between the two – there is an overlap between the upper and lower bound of the two groups and a difference of 0.1-0.5 mm may be just a measurement error. If pathologic changes were to occur, it would most likely happen in the second decade of life and is most frequently a dentigerous cyst. Surgical enucleation and biopsy is required to diagnostically confirm the presence of a dentigerous cyst.[19]

Previously, several studies have focused on the effects of the dental follicle in association with root resorption of the neighboring adjacent teeth. It was seen that the follicle of the maxillary canine does not cause root resorption of the adjacent incisors but is most likely a result of the physical contact of the canine and the incisor, as well as the eruption process of the canine.[14,23]

To our knowledge, no available studies directly assess the size and volume of the dental follicle of impacted teeth and its effects on the adjacent tooth position. With the potential compressive forces created by the dental follicle during tooth eruption, which could subsequently displace the adjacent teeth, this is a unique perspective on the possible effects of the impacted teeth and its associated dental follicle. This could warrant early intervention to manage dental follicles to avoid certain malocclusion traits.

2.2 Purpose

We conducted a scoping review (ScR) to identify all published articles measuring changes to the relative position of the adjacent teeth associated with the dental follicles of the impacted maxillary canines and maxillary/mandibular third molars. A ScR is indicated when a broad understanding of the available evidence is desired. Such a review type is not intended to answer a specific clinical question but to map out every related attempt to investigate a topic.

2.3 Methods

As published by Arksey and O'Malley in 2005, the five-stage methodological framework for scoping reviews was used to map out key concepts in the literature about how the dental follicle may affect the adjacent tooth positions and identify available evidence.[24]

2.3.1 Stage 1 – Identifying the Research Question

Our research question for this ScR is as follows: *Is there any literature assessing the effects of the dental follicle of impacted canines/cuspids and third molars on the adjacent tooth position?*

2.3.2 Stage 2 – Identifying Relevant Studies

The search strategy for this ScR involved searching through several electronic databases, grey literature, and reference lists. An extensive search was conducted on October 5, 2022. With the assistance of a librarian from the University of Alberta, the search strategy was created, refined, and reviewed to produce the most relevant results. The final search was applied to Ovid MEDLINE (1946 to present) and then revised with appropriate database–specific subject headings and syntax for Ovid Embase (1974 to present), Scopus, and Google Scholar. Refer to *Appendix A* for the tables illustrating the search strategy used for each database.

2.3.3 Stage 3 – Study Selection

The initial selection was extended to articles whose title or abstract mentioned the presence of dental follicles associated with canine or third molar impacted teeth in patients of any age range with any radiographic imaging modality and included the effects that the dental follicle has on the position of the adjacent teeth. Studies that were explicitly focused on root resorption of the adjacent teeth were excluded since this is not the review's primary focus.

All citations were collated and uploaded into EndNote 20 (Clarivate, London, United Kingdom) and Covidence (Veritas Health Innovation, Melbourne, Australia) software which automatically removes duplicate articles. Two reviewers independently screened titles and abstracts against the predetermined inclusion and exclusion criteria. If there were uncertainty or conflict during screening, it would be resolved through discussion. After the screening process, the full text of the selected articles was obtained and reviewed by the same two reviewers independently. When an agreement was not reached, reviewers consulted with a third reviewer.

2.3.4 Stage 4 – Charting the Data

The two reviewers independently recorded and charted the following data using Microsoft Excel (Microsoft Corporation, Washington, United States) software, including author (s), year of publication, the aim of the study, study design, and important results.

2.3.5 Stage 5 – Collating, Summarizing and Reporting the Results

The results were analyzed, and the findings of this review were reported using a narrative account along with diagrams and descriptive summaries.

2.4 Results

A total of 1579 citations were identified, and 754 were reviewed after removing 825 duplicate citations. Seven hundred fifty-two citations did not meet the inclusion criteria and were excluded. The full-text articles of the remaining two citations were reviewed, and both articles were excluded due to improper study design. Therefore, there were no articles that were included in this scoping review that directly matched our inclusion criteria. This is illustrated in *Figure 2.1*.

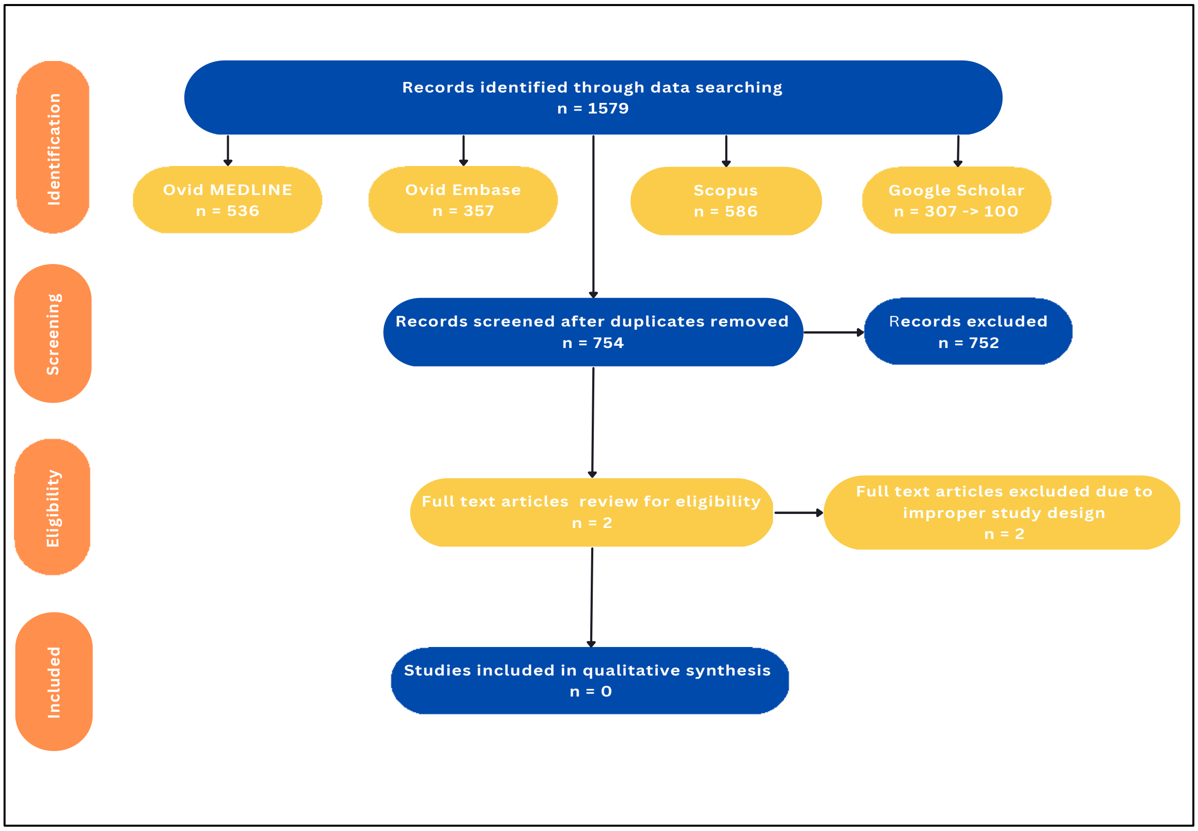


Figure 2.1 – Scoping review search flow chart

2.5 Discussion/Conclusion

Based on the results of our ScR, there are no articles that directly assess the effects of the dental follicle of the impacted canine and third molars on the relative position of the adjacent teeth. Many of the articles screened had focused on dental follicle sac dimensions related to impacted tooth position and orientation, as well as root resorption in the adjacent teeth, but not specifically on adjacent teeth displacement.

Tooth eruption is a complex process involving intricate steps, some of which are still poorly understood. It is generally divided into the pre- and post-emergent eruption phases, distinguished by the tooth's presence in the oral cavity. For the pre-emergent eruption phase, two processes are essential where first, resorption of the bone and primary tooth roots must occur and second, a propulsive mechanism that moves the developing tooth along this path.

Once the crown formation is complete, genes responsible for bone remodelling above the crown are signalled and activated as well as the removal of the inhibition of genes responsible for root formation. Many progenitor cells that are required for resorption are in the dental follicle. It is important to note that bone and primary root resorption is the rate-limiting process, and that clearance of an eruption path is key for pre-emergent eruption.

The propulsive mechanism of the tooth moving along the eruption path is still poorly understood. However, there have been different proposed theories, including the cross-linking of the mature collagen of the periodontal ligament, localized variation in blood pressure or flow at the end of the developing root, the proliferation of the pulpal cells, root formation/elongation, and alveolar bone growth/remodelling.

During the post-emergent eruption, once the tooth has emerged into the oral cavity, it erupts rapidly until it reaches the occlusal level, also referred to as the post-emergent spurt, and slows down once it is in function, referred to as the juvenile occlusal equilibrium (during pubertal growth). During eruption at this stage, the collagen fibres of the periodontal ligament become more oriented, where the collagen matures its cross-links and shortens, creating a propulsive force. At this point, the teeth tend to erupt in conjunction and compensate for the mandible's vertical growth. When the pubertal growth spurt ends, the teeth are now in the adult occlusal equilibrium phase, where the teeth erupt at an extremely slow rate.[1]

The dental follicle is generally lost after the tooth has emerged in the oral cavity, either by the transformation in the junctional epithelium or apoptosis.[22] When the maxilla or mandible does not have enough space to accommodate eruption, it often leads to crowding and, if severe enough, leads to tooth impaction.

As mentioned before, the dental follicle is a vascular fibrous, loose connective tissue sac that encapsulates the crown of the erupting tooth that inserts at the cementoenamel junction. It is a key component in the eruptive process of the developing tooth as it contains osteoblasts that differentiate into osteoclasts that mediate bone remodelling. The dental follicle of maxillary canines typically expands to a width of 2.3-3.2 mm, depending on whether the tooth erupts normally or ectopically. With this expansile nature of the dental follicle, it would be reasonable to question if it creates sufficient outward pressure on the surrounding structures, such as deviation of the roots of adjacent teeth during tooth eruption. Since the dental follicle has the potential to become hyperplastic or even pathologic and occupy more space within the trabecula of the maxilla that is confined by the denser cortical plate, the size/volume of the dental follicle could have a role in the degree of displacement of adjacent tooth root positions if there is sufficient pressure generated.[19,22] We hypothesize that the dental follicle of the impacted maxillary canine can generate forces capable of displacing the adjacent teeth, and the degree of displacement could correlate to the varying size/volume of the follicle. This could result in malocclusion traits that may warrant the early intervention of the dental follicle.

Interestingly, when reviewing the full-text articles for this scoping review, there was only a brief mention in the discussion of the study by Ericson and Bjerklin (2001) about their thoughts on the effects of the dental follicle on the relative position of the adjacent teeth, even though it was not their focus.[19] Their study primarily focused on the dimensions of the dental follicle based on the impacted maxillary canine position. It was stated that the follicle often expands into the loose spongious bone in proximity to the roots of the adjacent teeth and is typically displaced near an ectopically positioned canine. The authors believe that the deviation in position is most likely due to the eruptive force of the canine and not by the dental follicle itself. However, they also indicate that they cannot confirm if widened dental follicles during maxillary canine eruption increase the risk of adjacent incisor root displacement.[19] We believe that the hydrostatic force of the expanding dental follicle has the potential to displace adjacent teeth.

Traditionally, the radiographic views commonly used for assessing impacted teeth included periapical (with the SLOB rule), maxillary occlusal, panoramic, and lateral cephalometric radiographs that provided limited 2D information of the structures of interest. With the ongoing technological advancement in dentistry, CBCT has provided a 3D insight into impacted teeth, especially in cases of root resorption of the adjacent teeth and eliminated the problems with superimposition and magnification seen in conventional radiography.[12]

Studies comparing advanced imaging modalities and panoramic radiographs showed differences in favor of CBCT when looking at impacted maxillary canine labio-palatal cusp position, mesiodistal apex position and adjacent teeth resorption. Subsequently, there have been mixed results on whether there is a significant influence on the overall treatment plan when using the various radiographic methods, which brings to question whether routine CBCT is warranted in treating most of these cases.[14] Nevertheless, there seems to an overall consensus that for impacted teeth CBCT imaging is justified as long as the benefits outweigh the risks of exposing the patient to further radiation and if the information provided by 2D imaging modalities is insufficient for diagnosing and treatment planning.

In conjunction with 3D advanced imaging modalities, commercially available imaging/viewing software has allowed clinicians to gain more insight into dental structures that were not accessible before. For example, the dimensions of the dental follicle of impacted teeth were traditionally assessed by measuring the largest distance from the tooth's crown to the periphery of the follicle on axial computed tomography slices or 2D radiographs.[19] Imaging software has the function to generate volumetric measurements by manually or automatically segmenting and highlighting the isotropic voxels of the structure of interest and creating a 3D rendering where the volume can be calculated. These optimization tools allow clinicians to dive into new areas of research that were not previously available or thought of to pursue.

With limited literature and evidence available on the ScR topic, there is a gap in knowledge about dental follicles of impacted teeth that requires further investigation.

Appendix A

Table A.1 – Ovid Medline

<(946 to October 5, 2022) Date Searched – October 5, 2022 Results: **536**	1. Dental Sac/ 2. dental sac*.mp. 3. Tooth Germ/ 4. tooth germ*.mp. 5. dental follicle*.mp. 6. connective tissue sac*.mp. 7. Cuspid/ 8. cuspid*.mp. 9. canine*.mp. 10. Molar, Third/ 11. third molar*.mp. 12. 3rd molar*.mp. 13. (wisdom tooth or wisdom teeth).mp. 14. 1 or 2 or 3 or 4 or 5 or 6 15. 7 or 8 or 9 16. 10 or 11 or 12 or 13 17. 14 and (15 or 16)

Table A.2 – Ovid Embase

<(974 to October 5, 2022) Date Searched – October 5, 2022 Results: **357**	1. tooth sac/ 2. dental sac*.mp. 3. Tooth Germ/ 4. tooth germ*.mp. 5. dental follicle*.mp. 6. connective tissue sac*.mp. 7. canine tooth/ 8. cuspid*.mp. 9. canine*.mp. 10. third molar/ 11. third molar*.mp. 12. 3rd molar*.mp. 13. (wisdom tooth or wisdom teeth).mp. 14. 1 or 2 or 3 or 4 or 5 or 6 15. 7 or 8 or 9 16. 10 or 11 or 12 or 13 17. 14 and (15 or 16)

Table A.3 – Scopus

Date Searched – October 5, 2022 Results: **586**
(TITLE-ABS-KEY ("dental follicle" OR "dental sac" OR "tooth germ" OR "connective tissue sac")) AND ((TITLE-ABS-KEY ("cuspid" OR "canine")) OR (TITLE-ABS-KEY ("third molar" OR "3rd molar" OR "wisdom tooth" OR "wisdom teeth")))

Table A.4 – Google Scholar

Date Searched – October 5, 2022 Results: **307**
With all of the words: “dental follicle” “dental sac” With at least one of the words: canine cuspid “third molar” “wisdom tooth” Note: Only the first 100 results were included, as search specificity was limited.

Chapter 3

Methodology

3.1 Methods

3.1.1 Sample Selection

Data collection for this study was obtained from a pool of available pre-treatment CBCT records of patients with unilateral palatally impacted maxillary canines, where the contralateral normally erupted canine was designated as the control. These records were obtained from:

- The University of Alberta Faculty of Medicine and Dentistry - Orthodontic Clinic (Canada)
- Universita degli Studi della Campania Luigi Vanvitelli - Diparmento Multidisciplinare di Specialità Medico-Chirurgiche e Odontoiatriche (Italy)
- The Hebrew University - Hadassah School of Dental Medicine (Israel)
- University of Gothenburg - Sahlgrenska Academy - Department of Orthodontics (Sweden)

The final sample was selected based on the following eligibility criteria:

- Inclusion Criteria
    - Patients of any age group
    - Unilateral palatally maxillary impacted canines with the presence of the dental follicle
    - The dental follicle of the palatally impacted maxillary canine contacting the lateral incisor and/or the first premolar
    - Lateral incisor and first premolar teeth that are fully erupted
    - CBCT imaging includes the maxilla as well as both impacted and normally erupted contralateral canine and adjacent teeth.
- Exclusion Criteria
    - Diagnosed craniofacial congenital anomalies or syndromes

- Missing lateral incisor or first premolar
- Pathologies associated with impacted canine or adjacent teeth
- Patients that have reported significant facial trauma
- Previous orthodontic treatment that affect the position of the maxillary dentition
- CBCT scans with suboptimal resolution and excessive artifacts compromise the evaluation of the maxillary canine and follicular sac

Based on the study by Dekel et al. (2021), a mean difference of 5 degrees between the torque angular measurements of the lateral incisor and first premolar adjacent to the palatally impacted maxillary canine and the controls was considered clinically relevant. From their pilot study, a standard deviation of 6.4 degrees was accepted with a 0.05 significance level and a power of 80%.[7] The minimum sample size was determined to be 26 patients.

The following CBCT systems were used to scan the patients:

- i-CAT 17-19 (Imaging Sciences International; Hatfield, PA)
- Orthophos XG 3D (Sirona; Bensheim, Germany)
- Newtom 5G/ 5G XL/ VGi Evo (Newtom; Bologna, Italy)
- Somatom Emotion 16 (Siemens Healthineers; Erlangen, Germany)

The scans were taken at a range of 0.25 – 0.4 mm^3 over 2 - 8.9 seconds (75 - 120kVp; 5mA) and included the field of views that captured the maxilla and dentition of interest to allow for proper measurements in the study.

3.1.2 Segmentation of the Dental Follicle

For this study, volumetric segmentation of the dental follicle of the impacted maxillary canine was performed using the open-source software OsiriX DICOM Viewer (version 13.01). This imaging software has been used in studies involving both the dental and medical fields for volumetric analysis.[25-27] The DICOM files of each patient were obtained and imported into OsiriX, and a manual segmentation process was employed. The decision to use a manual segmentation process was due to the soft tissue nature of the dental follicle and the inability of the automated processes to discern the borders of the dental follicle. This would often cause the seed voxel to connect undesirable areas and leak into the surrounding structures, such as the oral cavity or other less radiopaque structures. Previous studies had implemented these segmentation techniques on hard tissue structures such as dentition, which had more clarity in terms of structural mass and borders. Prior to the segmentation of the dental follicle, it was determined that the sagittal view of the CBCT provided the clearest view of the dental follicle in relation to the crown of the impacted canine. The axial and coronal views were later used to confirm the accuracy of the segmentation. Manual segmentation involved utilizing tools within OsiriX such as “paintbrush”, “pencil”, and “repulsor” to freehand trace the voxels that generated the dental follicle to highlight the region of interest (referred to as “ROI” on OsiriX). This was repeated for each DICOM image slice-by-slice until the entire dental follicle was captured into the region of interest in which the 3D model would be rendered. The crown of the impacted canine was excluded from the region of interest to determine the true volume of the dental follicle.

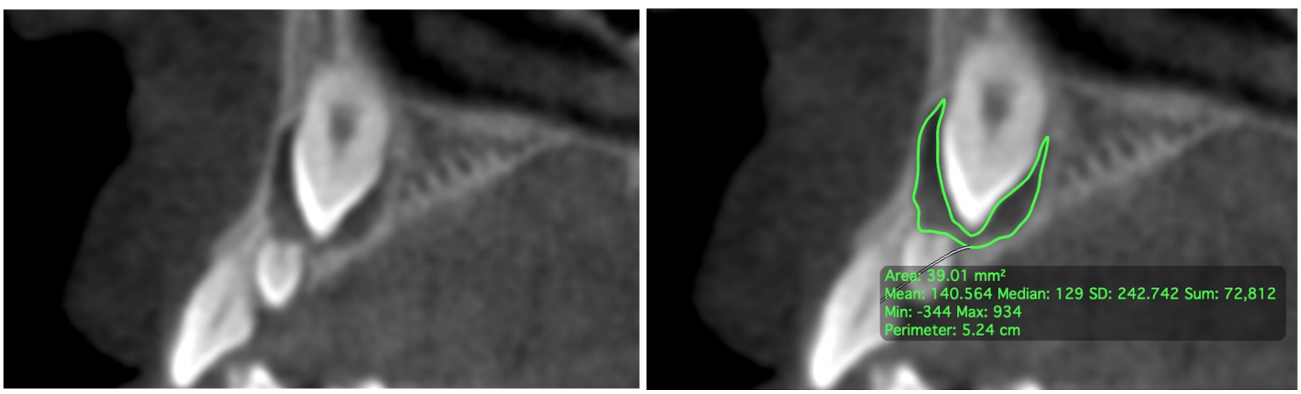


Figure 3.1 – Segmentation of the dental follicle of the maxillary impacted canine using OsiriX DICOM Viewer in the sagittal view of the CBCT. This method of tracing was manually repeated and refined for each slice of the DICOM containing the dental follicle.

3.1.3 Measurement of the Dental Follicle

To obtain the measurement of the dental follicle volume, the entire region of interest must be established from the DICOM images containing the desired portion of the dental follicle, as mentioned in the previous steps. Since a voxel is an isotropic 3D element represented as a cube or box, any voxel that is highlighted in the region of interest will highlight the volume in not only the sagittal view but also the axial and coronal views of the CBCT. In *Figure 3.1*, the area is generated for each slice, as seen in the label indicating that the area is 39.01 $mm^{2,}$ and the volume can be calculated by compiling each slice containing the region of interest (ROI). The “ROI” function is accessed in the toolbar where the “ROI Volume” and then the “Compute

Volume" options can then be selected. The volume of the region of interest will then be generated in cm^3 units. This can be seen in *Figure 3.2*.

Figure 3.2 – Completed 3D rendering of the dental follicle of the impacted maxillary canine with the associated volumetric calculation. As shown in the photo, the dental the follicle has a volume of 0.2525 cm^3 or 252.5 mm^3.

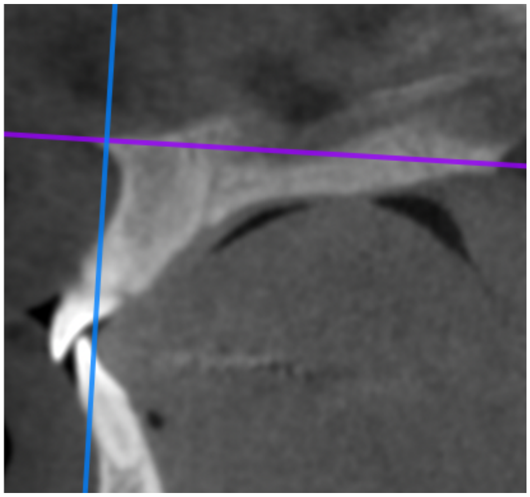
3.1.4 Measurement of the Relative Position of the Adjacent Teeth

3.1.4.1 Establishment of the Palatal Reference Plane

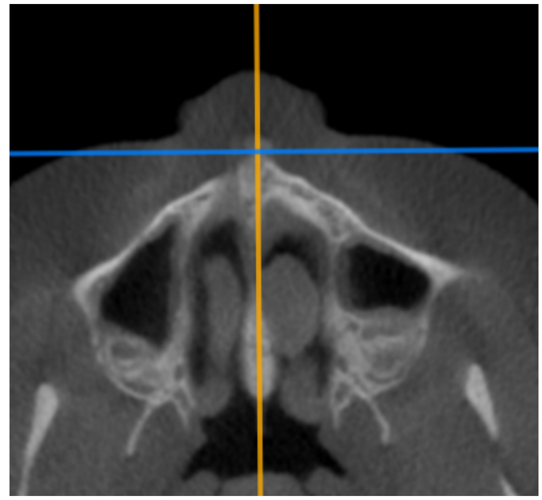
Based on the methodology used by Dekel et al. (2021), the palatal plane was used as the reference plane to measure the angular tip, torque, and rotation of the adjacent lateral incisor and first premolar.[7] The palatal plane acts as a stable reference point that can be standardized in the axial, coronal and sagittal views based on a line that runs through the anterior nasal spine (ANS) to the posterior nasal spine (PNS).

The following reference planes are shown in *Figure 3.3* and are as follows:

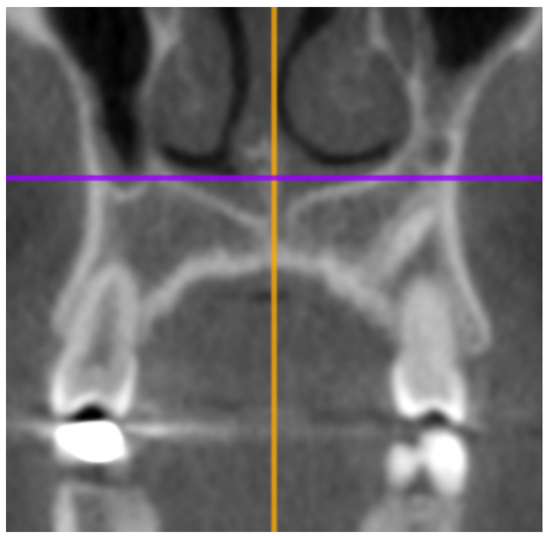
- Palatal Plane (Sagittal): a horizontal plane connecting ANS and PNS
- Midpalatal Plane (Axial): a vertical plane connecting ANS and PNS that runs perpendicular to the horizontal plane
- Vertical plane (Coronal): a plane that runs through ANS oriented perpendicular to the palatal and midpalatal plane



a) Sagittal View of the CBCT



b) Axial View of the CBCT



c) Coronal View of the CBCT

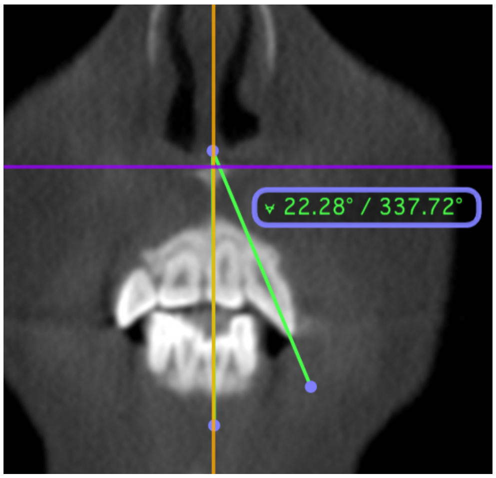
Figure 3.3 – Multiplanar reconstruction views demonstrating the palatal reference planes. The palatal plane is represented by the purple line; the Midpalatal plane is represented by the yellow line; the Vertical plane is represented by the blue line.

3.1.4.2 Measurement of the Relative Position of the Lateral Incisor

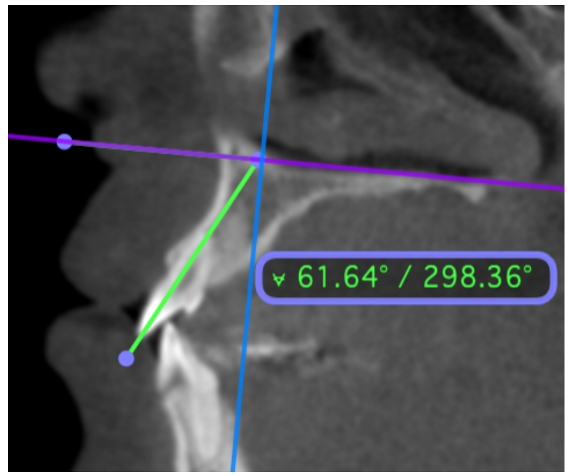
Utilizing the palatal plane as the reference point, the lateral incisor adjacent to the impacted canine and control was measured, shown in *Figure 3.4* and are as follows:

- Mesiodistal Tip – measured in the coronal view – the angle between the long axis of the lateral incisor and midpalatal plane (yellow line).

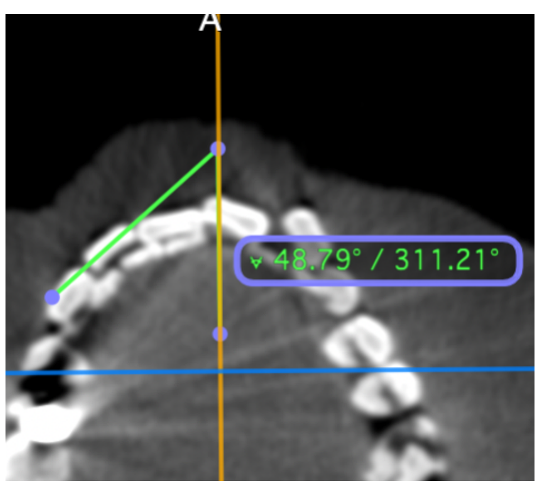
- Buccolingual Torque – measured in the sagittal view – the angle between the long axis of the lateral incisor and palatal plane (purple line)
- Mesiodistal Rotation – measured in the axial view – the angle between a tangent bisecting the most prominent mesiodistal contour (parallel to the facial surface) of the lateral incisor and the midpalatal plane (yellow line).



a) Mesiodistal Tip



b) Buccolingual Torque



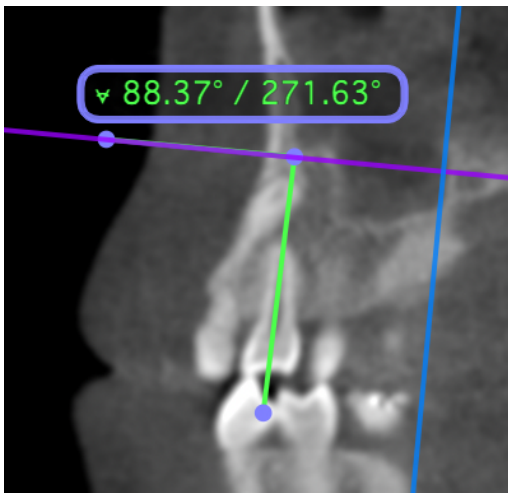
c) Mesiodistal Rotation

Figure 3.4 – Multiplanar reconstruction views demonstrating the angular measurements of the lateral incisor.

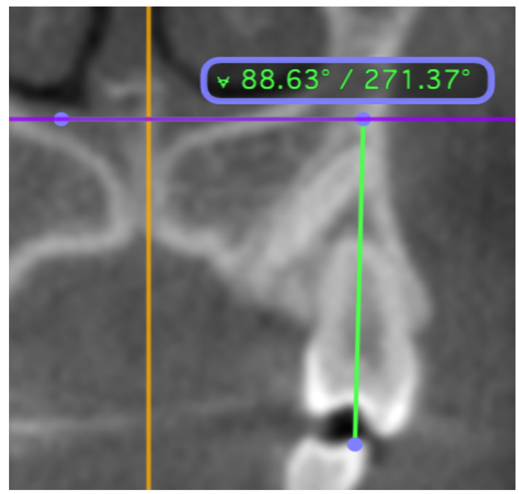
3.1.4.3 Measurement of the Relative Position of the First Premolar

Utilizing the palatal plane as the reference point, the first premolar adjacent to the impacted canine and control was measured, shown in *Figure 3.5* and are as follows:

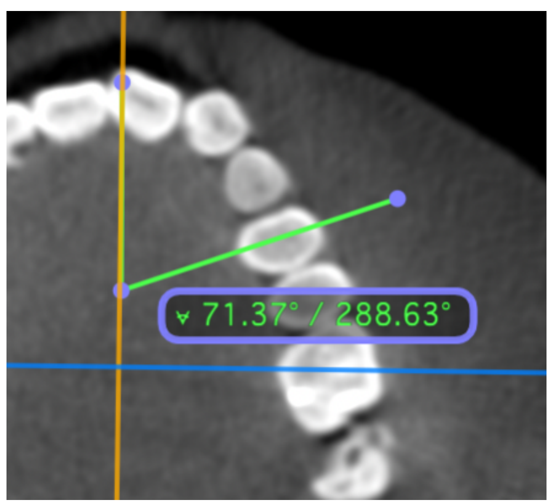
- Mesiodistal Tip – measured in the sagittal view – the angle between the long axis of the first premolar and palatal plane (purple line).
- Buccolingual Torque – measured in the coronal view – the angle between the long axis of the first premolar and midpalatal plane (yellow line)
- Mesiodistal Rotation – measured in the axial view – is the angle between a tangent bisecting the buccolingual surface of the first premolar and the midpalatal plane (yellow line).



a) Mesiodistal Tip



b) Buccolingual Torque



c) Mesiodistal Rotation

Figure 3.5 – Multiplanar reconstruction views demonstrating the angular measurements of the first premolar.

3.1.5 Statistical Reliability of Methods

Ten patients for intra-rater and six patients for inter-rater reliability were randomly selected from a collected sample pool of 49 patients to determine the method reliability for the measurement of the dental follicle volume of the impacted maxillary canine. These patients were randomly selected using Microsoft Excel (Microsoft Corp., Redmond, WA., USA). Intraclass Correlation Coefficient (ICC) was used to measure agreement between the measurements for the principal investigator (M.L.). A two-way mixed model with measures of consistency was chosen under the circumstances that the patients were selected at random and that the rater remained fixed. Interclass Correlation Coefficient (ICC) was used to measure the agreement between the principal investigator's measurements and the two additional investigators' measurements. A two-way mixed model with the absolute agreement was chosen under the circumstances that the patients were selected at random and that the raters remained fixed.[28]

To assess intra-rater reliability, the principal investigator M.L. performed the segmentation protocol of the dental follicle volume and angular measurements of the adjacent teeth for the ten randomly selected patients at three separate time intervals one week apart.

To assess inter-rater reliability, two orthodontists (L.N. and E.D.) were trained and familiarized with how to perform the segmentation protocol for the dental follicle volume of the impacted maxillary canine. The additional investigators measured six randomly selected patients at two instances one week apart, which were also measured by the principal investigator. The inter-rater reliability for the angular measurements of the adjacent lateral incisor and first premolar was not performed as the method utilized was adapted from the study by Dekel et al. in 2021, and the reported reliability values assumed – the same researchers involved in both projects.[7] The intraclass correlation coefficient (ICC) for their study showed excellent reliability (ICC > 0.90) for the angular measurements, and two of the primary investigators of that study are currently involved with this thesis.

Statistical analysis was performed using IBM SPSS Statistics for Apple Mac OS (Version 28). The significance level was set to $\alpha = 0.05$ for all statistical analyses used. ICC reliability with a 95% confidence interval is classified as poor (ICC < 0.50), moderate (0.50 < ICC < 0.75), good (0.75 < ICC < 0.90), and excellent (ICC > 0.90) reliability.[28]

3.1.6 Hypothesis Testing

The study was designed to have the following:

- Three dependent variables (continuous)
  - Mesiodistal tip – the difference between the impacted and control sides of the adjacent lateral incisor or first premolar (measured in degrees)
  - Buccolingual torque – the difference between the impacted and control sides of the adjacent lateral incisor or first premolar (measured in degrees)
  - Mesiodistal rotation – the difference between the impacted and control sides of the adjacent lateral incisor or first premolar (measured in degrees)
- One independent variable (continuous):
  - Dental Follicle Volume

A **Multivariant Regression Analysis** was determined to be the appropriate test. The following null hypotheses and alternate hypotheses were tested with the Multivariant Regression Analysis:

- H_0 = there is no difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the lateral incisor between the impacted and control sides when comparing the volume of the dental follicle as it contacts the lateral incisor.
- H_a = there is a difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the lateral incisor between the impacted and control sides when comparing the volume of the dental follicle as it contacts the lateral incisor.
- H_0 = there is no difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the first premolar between the impacted and control sides when comparing the volume of the dental follicle as it contacts the first premolar.
- H_a = there is a difference in the mean change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the first premolar between the impacted and control sides when comparing the volume of the dental follicle as it contacts the first premolar.

Refer to *Appendix B* for further details on data and specifics associated with hypothesis testing.

Appendix B

Assumptions Testing for the Multivariant Regression Analysis:

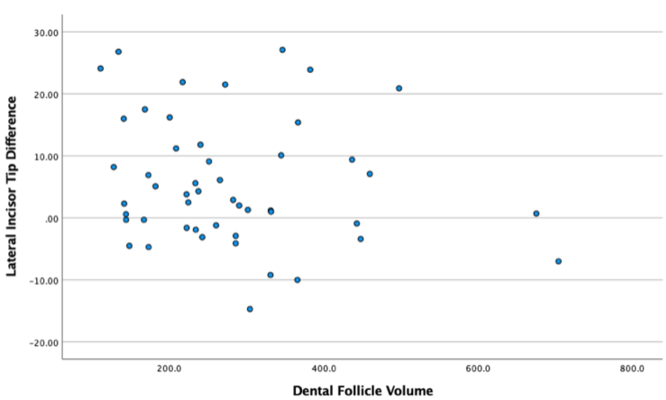
Due to the presence of noisy data, it was difficult to meet the following assumptions without some subjective interpretation. Transforming the data did not show any improvement in the data set. The lateral incisor sample had 49 patients and the first premolar sample had 23 patients.

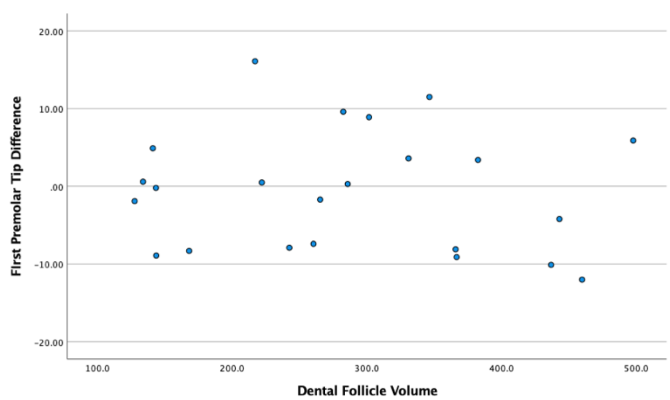
The data was sampled independently where observation of one group cannot influence the other for both the lateral incisor and first premolar samples.

The assumption of linearity between the difference in tip, torque, and rotation of the adjacent lateral incisor and first premolar between the impacted and control sides plotted against the dental follicle volume has been met based on visual inspection of the scatter plots. The scatterplots are shown in *Figure B.1*.

Boxplots for the difference in tip, torque, and rotation of the adjacent lateral incisor and first premolar between the impacted and control side were completed to visually assess the distribution and normality of the data (shown in *Figure B.2*). Based on the plots, the lateral incisor tip, and torque as well as the first premolar tip appear to be normally distributed. The lateral incisor rotation appears left skewed as the whisker is longer towards the bottom with an outlier. The first premolar torque and rotation are right skewed as whisker is long towards the top with an outlier.

Figure B.1 – Scatterplots of the difference in tip, torque and rotation (measured in degrees) of the adjacent lateral incisor and first premolar between the impacted and control sides plotted against the dental follicle volume (measured in mm^3).





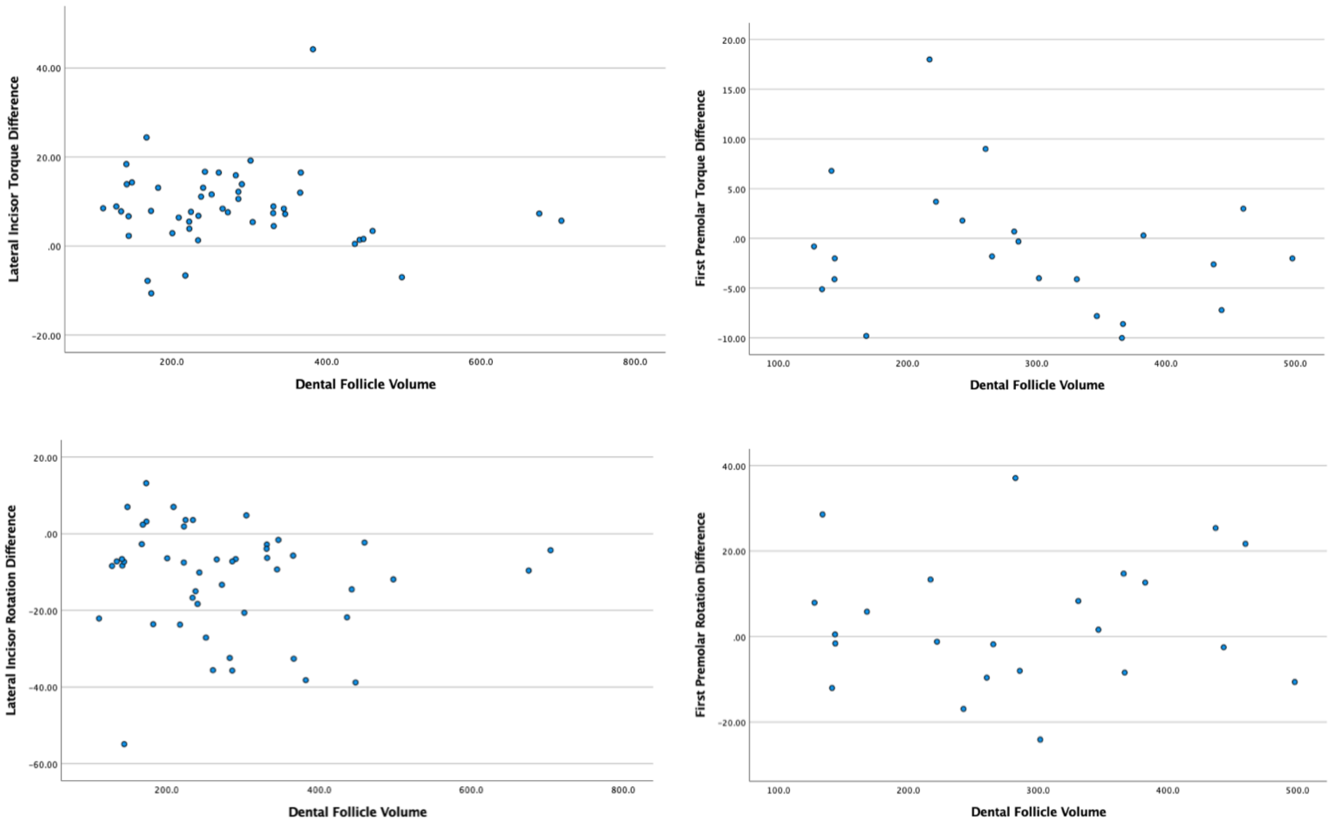
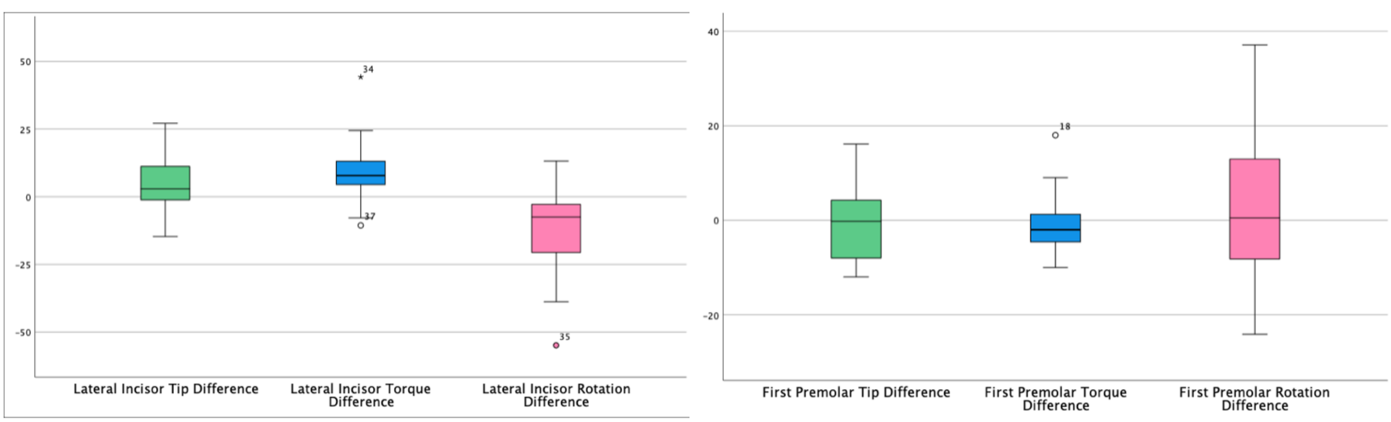
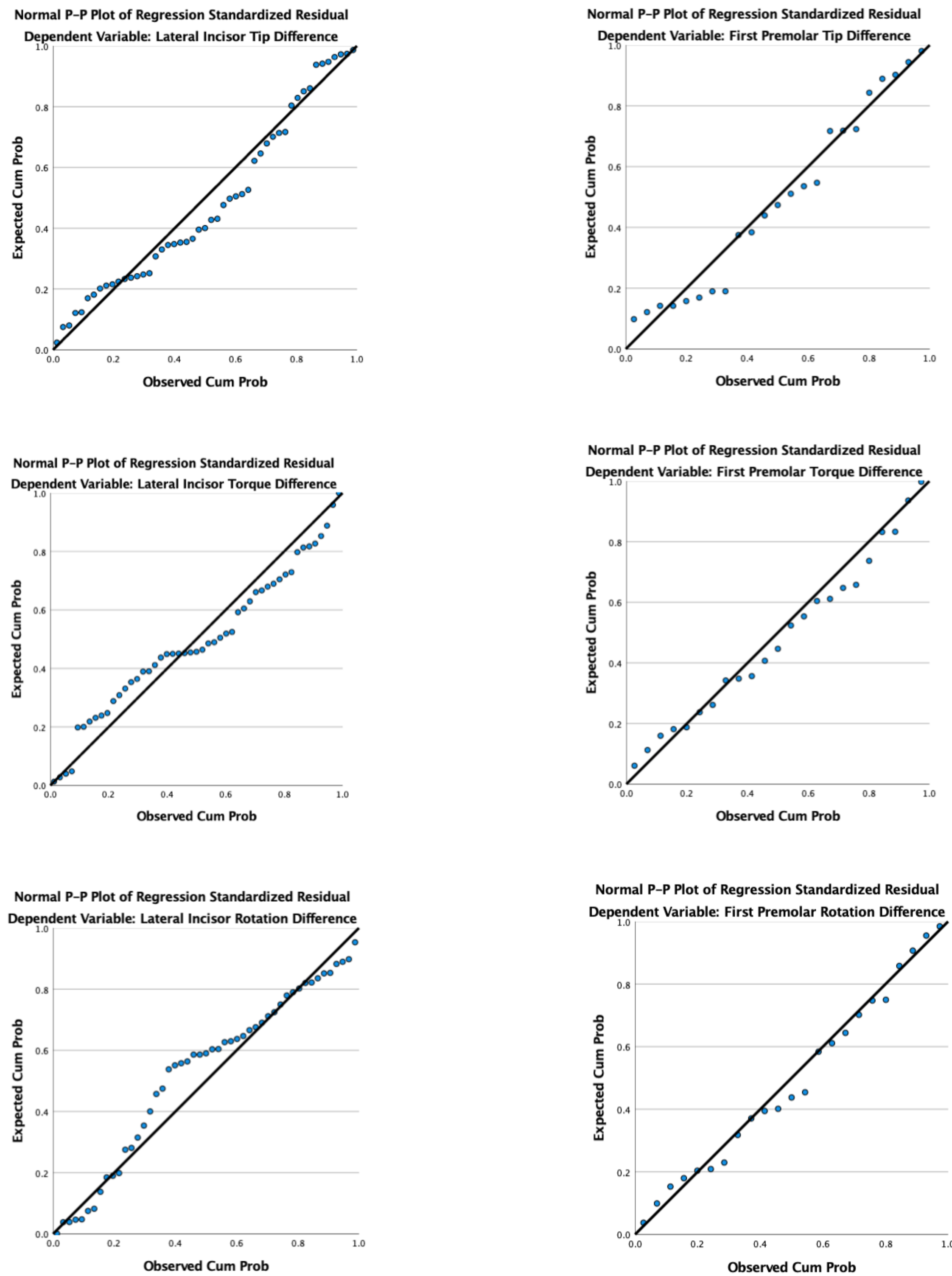


Figure B.2 – Boxplots for the difference in tip, torque, and rotation (measured in degrees) of the adjacent lateral incisor and first premolar between the impacted and controls sides.



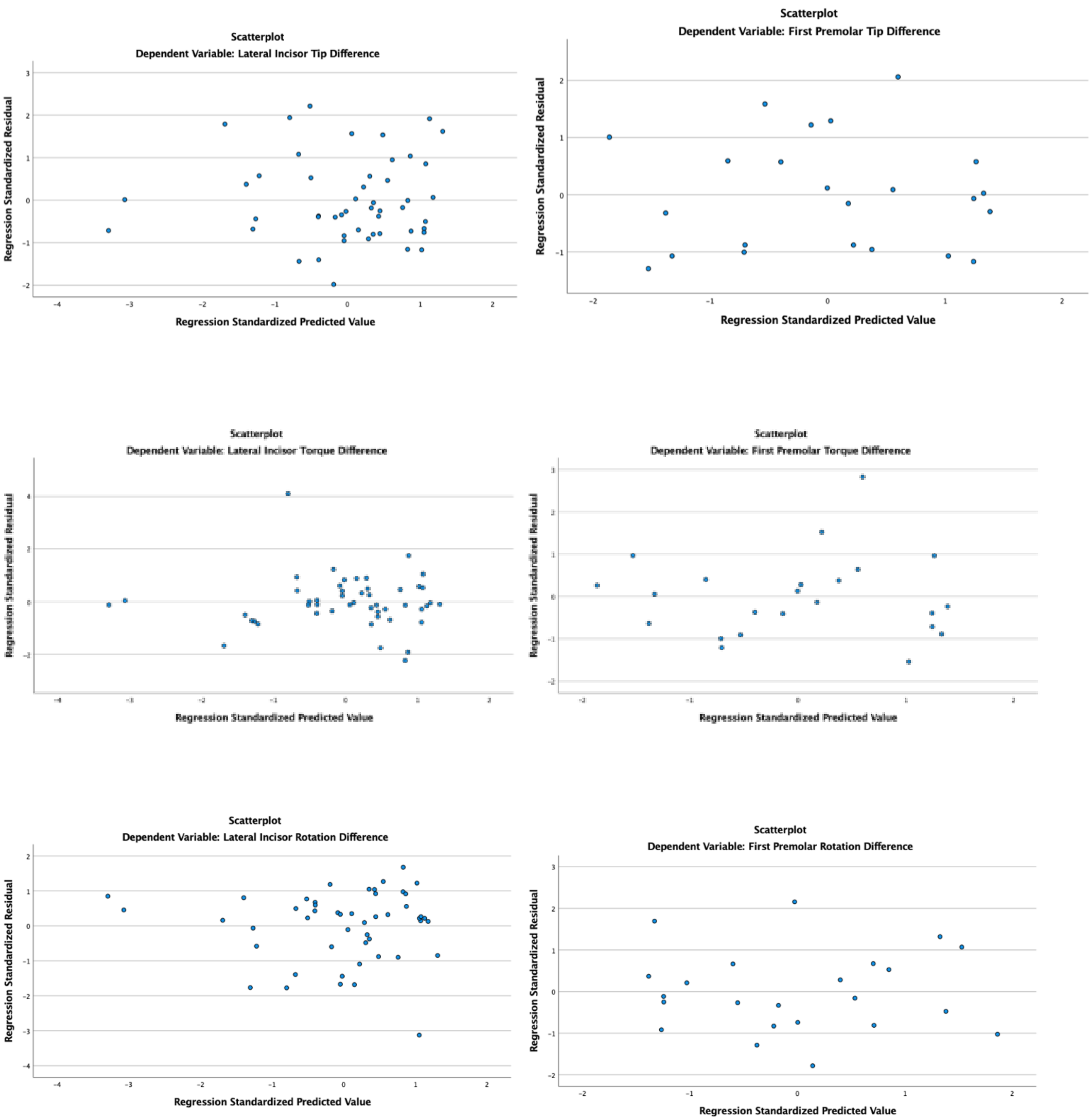
Normality P-P plots for the difference in tip, torque, and rotation of the adjacent lateral incisor and first premolar between the impacted and control sides were completed to also assess the distribution and normality of the data (shown in *Figure B.3*). Overall, the residuals of the data appear to fall along the diagonal line except for the lateral incisor rotation showing deviation to the left of the line. Generally, the multivariant regression analysis is robust against deviations from normality as long as the sample size is large and equal, which applies to both samples; however, the first premolar sample is below the minimally required sample size.

Figure B.3 – Normality P-P plots of the difference in tip, torque and rotation of the adjacent lateral incisor and first premolar between the impacted and control sides.



There was no violation of homoscedasticity, as assessed by visual inspection of scatterplots of the standardized residuals plotted against the standardized predicted values for each dependent variable (shown in *Figure B.4*).

Figure B.4 – Scatterplots of the standardized residual values plotted against the standardized predicted values of the difference in tip, torque, and rotation of the adjacent lateral incisor and first premolar between the impacted and control sides.



Chapter 4

Results

4.1 Reliability of Measurements

4.1.1 Intra-Rater Reliability

The results of the ICC with 95% CI can be seen in *Table 4.1*. The raw data collected for the volumetric measurements of the dental follicle and angular measurements of the adjacent teeth for the intra-rater reliability (ten patients three times – one week apart) can be seen in *Tables C.1 –C.4* of *Appendix C.* The statistical tests ran on SPSS software can be seen in *Figure C.1* of *Appendix C.*

Measurement Type	ICC [95% CI]
Dental Follicle Volume	0.979 [0.940 - 0.994]
Lateral Incisor Tip	0.921 [0.844, 0.965]
Lateral Incisor Torque	0.971 [0.941, 0.988]
Lateral Incisor Rotation	0.995 [0.989, 0.998]
First Premolar Tip	0.896 [0.796, 0.954]
First Premolar Torque	0.861 [0.734, 0.937]
First Premolar Rotation	0.936 [0.871, 0.972]

Table 4.1 – ICC with 95% CI for the intra-rater reliability

The ICC for the volumetric measurement of the dental follicle was **0.979** [0.940 – 0.994], which demonstrates excellent reliability (ICC > 0.90). The ICC for the angular measurement of the adjacent lateral incisor tip, torque, and rotation, and the first premolar rotation were **0.921** [0.844, 0.965], **0.971** [0.941, 0.988], **0.995** [0.989, 0.998] and **0.936** [0.871, 0.972] respectively, which demonstrates excellent reliability (ICC > 0.90). The ICC for the angular measurement of the adjacent first premolar tip and torque were **0.896** [0.796, 0.954] and **0.861** [0.734, 0.937], respectively, which demonstrates good reliability (0.75 < ICC < 0.90).

Impacted Canine Side

The measurement error and percent measurement error of the volumetric measurement of the dental follicle and angular measurements of the adjacent lateral incisor and first premolar can be seen in *Tables C.5 and C.*6 of *Appendix C.* The percent measurement error for the dental follicle volume varied between 2.7% to 9.7% (11.9 mm^3 to 20.5 mm^3). The percent measurement error for the angular measurements of the lateral incisor tip, torque, and rotation on the impacted canine side varied between 4.1% to 22.4% (0.7 degrees to 3.3 degrees), 0.8% to 5.2% (0.7 degrees to 4.1 degrees), and 1.4% to 8.1% (0.7 degrees to 3.3 degrees), respectively. The percent measurement error for the angular measurements of the first premolar tip, torque and rotation on the impacted canine side varied between 1.2% to 4.5% (1.3 degrees to 3.9 degrees), 0.2% to 3.1% (0.2 degrees to 3 degrees), and 0.1% to 3.5% (0.2 degrees to 2.9 degrees), respectively.

Control Side

The percent measurement error for the angular measurements of the lateral incisor tip, torque, and rotation on the control side varied between 4.9% to 45.8% (0.4 degrees to 4.4 degrees), 1.0% to 4.9% (0.9 degrees to 3.1 degrees), 1.0% to 7.0% (0.3 degrees to 3.1 degrees), respectively. The percent measurement error for the angular measurements of the first premolar tip, torque, and rotation on the control side varied between 0.9% to 8.4% (0.9 degrees to 7.6 degrees), 2.0% to 5.9% (1.9 degrees to 5.4 degrees), and 0.4% to 5.2% (0.3 degrees to 3.7 degrees), respectively.

4.1.2 Inter-Rater Reliability

The raw data collected for the volumetric measurements of the dental follicle (seven patients at two-time intervals – one week apart) for the three investigators (ML, LN and ED) for the inter-rater reliability can be seen in *Table C.7* of *Appendix C.* The statistical tests ran on SPSS software can be seen in *Figure C.2* of *Appendix C*. The inter-rater reliability for the angular measurements of the adjacent lateral incisor and first premolar was not performed as the method was adapted from the study by Dekel et al. in 2021, and the reported reliability values were obtained.[7] The ICC for their study showed excellent reliability (ICC > 90) for the angular measurements, and two of the primary investigators of that study are currently involved with this thesis.

The ICC for the volumetric measurement of the dental follicle for the three investigators was **0.876** [0.707, 0.973], which demonstrates good reliability (0.75 < ICC < 0.90).

The measurement error and percent measurement error of the volumetric measurement of the dental follicle for the three investigators can be seen in *Table C.8* of *Appendix C*. The percent measurement error for the volumetric measurement of the dental follicle for the three investigators, ML, LN, and ED, varied between 1.1% to 5.5% (7.6 mm^3 to 14.9 mm^3), 1.6% to 7.7% (6.9 mm^3 to 30.6 mm^3), and 1.1% to 11.4% (3.7 mm^3 to 30.6 mm^3), respectively.

4.2 Descriptive Statistics

Forty-nine patients with previous CBCT records were assessed for this study. Descriptive statistics can be observed in *Table 4.2*.

Measurements	N	Mean	Minimum	Maximum	Standard Deviation	95% CI (Lower)	95% CI (Upper)
Dental Follicle Volume (mm^3)	49	279.6	110.7	704.1	128.9	242.5	316.6
Lateral Incisor Tip Difference (degrees)	49	5.6	-14.7	27.1	10.1	2.7	8.5
Lateral Incisor Torque Difference (degrees)	49	8.6	-10.6	44.2	8.7	6.1	11.1
Lateral Incisor Rotation Difference (degrees)	49	-11.6	-54.9	13.2	14.2	-15.9	-7.9
First Premolar Tip Difference (degrees)	23	-0.6	-12.0	16.1	7.8	-4.0	2.7
First Premolar Torque Difference (degrees)	23	-1.2	-10.0	18.0	6.5	-4.0	1.6
First Premolar Rotation Difference (degrees)	23	3.5	-24.1	37.1	15.2	-3.1	10.1

Table 4.2 – Descriptive statistics of the volumetric measurements of the dental follicle and angular measurements of the tip, torque, and rotation of the adjacent lateral incisor and first premolar.

4.3 Multivariant Regression Analysis

The results of the multivariant regression analysis (*Figure C.3* of *Appendix C*) for the lateral incisor sample ($n = 49$) suggest that there is not enough evidence ($p = 0.509$ with the outliers and $p = 0.110$ without the outliers) to reject the null hypothesis; therefore, the differences are not statistically significant. In other words, there is no difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent lateral incisor between the impacted and control sides when comparing the volume of the dental follicle when it contacts the lateral incisor.

The results of the multivariant regression analysis for the first premolar sample ($n = 23$) suggest that there is not enough evidence ($p = 0.804$ with the outliers and $p = 0.892$ without the outliers) to reject the null hypothesis; therefore, the differences are not statistically significant. In other words, there is no difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent first premolar between the impacted and control sides when comparing the volume of the dental follicle when it contacts the first premolar.

Appendix C

Table C.1 – Raw collected data of dental follicle volume for intra-rater reliability

Patient	Dental Follicle Volume Week 1	Dental Follicle Volume Week 2	Dental Follicle Volume Week 3
1	265.4	246.6	241.2
2	344.7	330.2	350.6
3	282.5	290.1	269.4
4	290.3	275.4	306.2
5	459.6	474.2	455.3
6	331.2	340.4	318.7
7	251.2	240.8	233.3
8	260.4	275.2	251.4
9	187.6	170.2	162.3
10	212.9	205.6	228.3

Table C.2 – Raw collected data of angular measurements for intra-rater reliability (week 1)

Patient	Canine Group	M/D Tip (L. Incisor) Week 1	B/L Torque (L.Incisor) Week 1	M/D Rotation (L. Incisor) Week 1	M/D Tip (F. Premolar) Week 1	B/L Torque (F. Premolar) Week 1	M/D Rotation (F. Premolar) Week 1
1	Impacted	14.3	74.5	46	93.3	93	75.3
2	Impacted	19.3	74.1	37.3	90.4	86.7	82
3	Impacted	11.7	79.1	74.5	98.6	94.6	100.8
4	Impacted	10.4	70.9	51.4	93.2	93.5	75.3
5	Impacted	17.2	69.9	60.1	80.9	98	90.9
6	Impacted	9	86.7	27.4	89.6	91.8	78.8
7	Impacted	20.7	77.4	26	86.9	89.6	64.9
8	Impacted	13.9	101.7	31.1	91.3	96.1	75.6
9	Impacted	16	73.4	41.4	78.2	99.1	80.9
10	Impacted	6.8	94	40.9	103.8	91.8	98.2
1	Control	8.2	66.1	52.7	95	94.8	77.1
2	Control	9.2	65.7	46.6	82.8	88.5	68.6
3	Control	8.8	63.2	106.9	89	93.9	63.7
4	Control	8.4	57	58	90.4	97.7	77.6
5	Control	10.1	66.5	62.4	92.9	95	69.2
6	Control	7.8	77.8	30.2	93.1	79.7	85.9
7	Control	11.6	65.8	53.1	91.9	99.5	74.3
8	Control	15.1	85.2	66.7	98.7	87.1	85.2
9	Control	13.5	65.7	37.8	84.6	92.6	73
10	Control	8.7	87.2	37.3	96.5	94.5	72.4

Table C.3 – Raw collected data of angular measurements for intra-rater reliability (week 2)

Patient	Canine Group	M/D Tip (L. Incisor) Week 2	B/L Torque (L.Incisor) Week 2	M/D Rotation (L. Incisor) Week 2	M/D Tip (F. Premolar) Week 2	B/L Torque (F. Premolar) Week 2	M/D Rotation (F. Premolar) Week 2
1	Impacted	18.7	77	48.3	96	97.3	78.2
2	Impacted	24.3	72.4	41.2	89.2	88.2	86.4
3	Impacted	15.3	76.1	76	97.5	94.5	100
4	Impacted	13	74.1	49.9	96	92.7	76.1
5	Impacted	21.3	68.5	60	77.7	94.7	87.2
6	Impacted	9.2	87.2	30	86.3	90.5	75.1
7	Impacted	22	80.1	26.5	89.1	87.2	63.9
8	Impacted	16.4	100	33.3	89.3	100.1	79
9	Impacted	18	73	39.9	81.3	98.9	80.8
10	Impacted	9.5	96.2	43.1	103.5	91.8	98.5
1	Control	7.8	69	56	93.3	93.2	74.5
2	Control	9.5	67.7	46.7	79.1	84.7	66.7
3	Control	13.3	65.2	108.5	91.4	90.1	62.4
4	Control	10	55.8	60	93.4	100.2	80.1
5	Control	12.6	68	64.2	94	94.9	74.5
6	Control	12.4	79	33.6	96	78.6	87.2
7	Control	13	67.1	56.2	92.2	103.4	78.9
8	Control	16.9	85.3	69.1	98.1	95.2	84.5
9	Control	14.8	66.1	37.4	81.4	90.1	73.2
10	Control	8.8	88.4	35.7	90.3	98	78.2

Table C.4 – Raw collected data of angular measurements for intra-rater reliability (week 3)

Patient	Group	M/D Tip (L.Incisor) Week 3	B/L Torque (L.Incisor) Week 3	M/D Rotation (L. Incisor) Week 3	M/D Tip (F. Premolar) Week 3	B/L Torque (F. Premolar) Week 3	M/D Rotation (F. Premolar) Week 3
1	Impacted	15.7	72.3	49.4	95	96	72.5
2	Impacted	22.4	77.8	42.2	87.2	86.1	84.2
3	Impacted	14.2	82.3	74.4	96.7	94.8	96.7
4	Impacted	13	74	51.5	93.6	93.5	74.9
5	Impacted	18	73	62.1	80.5	99.2	91.5
6	Impacted	10.1	86.2	30	85.7	94.1	78.8
7	Impacted	21.2	77.8	27	83.2	86.7	68.2
8	Impacted	13.7	105.4	29.8	91.8	100.2	70.2
9	Impacted	16.4	70.3	43.6	78.3	101	83
10	Impacted	7.8	91.1	40.2	102	93.2	101.2
1	Control	8.4	70.2	57	89.7	92	80.1

2	Control	10.3	69.2	51.2	80.2	90.1	68.4
3	Control	6.7	60.6	107.4	92	95.6	64.2
4	Control	10.5	57.8	57.4	88.7	94.6	77.3
5	Control	12.5	65.9	62.4	94.2	98	64.9
6	Control	7.4	82.2	33.2	95	75.6	88.1
7	Control	12	70	55.7	93.7	103.2	75.7
8	Control	17	86.7	68	100	91.2	89
9	Control	11.2	68.2	37.9	86.2	93.1	72.8
10	Control	10	88.5	38.9	85.1	94.3	68.8

Figure C.1 – Results of the ICC for the intra-rater reliability on IBM SPSS Statistics

Intraclass Correlation Coefficient – Dental Follicle Volume

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.979[a]	.940	.994	139.591	9	18	<.001
Average Measures	.993[c]	.979	.998	139.591	9	18	<.001

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – Lateral Incisor Tip

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.921[a]	.844	.965	36.208	19	38	.000
Average Measures	.972[c]	.942	.988	36.208	19	38	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – Lateral Incisor Torque

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.971[a]	.941	.988	102.317	19	38	.000
Average Measures	.990[c]	.979	.996	102.317	19	38	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – Lateral Incisor Rotation

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.995[a]	.989	.998	586.663	19	38	.000
Average Measures	.998[c]	.996	.999	586.663	19	38	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – First Premolar Tip

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.896[a]	.796	.954	26.725	19	38	<.001
Average Measures	.963[c]	.921	.984	26.725	19	38	<.001

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – First Premolar Torque

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.861[a]	.734	.937	19.578	19	38	<.001
Average Measures	.949[c]	.892	.978	19.578	19	38	<.001

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intraclass Correlation Coefficient – First Premolar Rotation

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.936[a]	.871	.972	44.784	19	38	.000
Average Measures	.978[c]	.953	.990	44.784	19	38	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table C.5 – Measurement error and percent measurement error of dental follicle volume for intra-rater reliability

Patient	Measurement Error (in mm^3) of Dental Follicle Volume	% Measurement Error of Dental Follicle Volume
1	16.1	6.4
2	13.6	4.0
3	13.8	4.9
4	20.5	7.1
5	12.4	2.7
6	14.5	4.4
7	11.9	4.9
8	15.9	6.1
9	16.9	9.7
10	15.1	7.0

Figure C.2 – Results of the ICC for the inter-rater reliability on IBM SPSS Statistics

Intraclass Correlation Coefficient – Dental Follicle Volume (ML, LN, ED)

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.876[a]	.707	.973	44.470	6	30	<.001
Average Measures	.977[c]	.935	.995	44.470	6	30	<.001

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table C.6 – Measurement error and percent measurement error of angular measurements of the adjacent lateral incisor and first premolar for intra-rater reliability

Patient	Adjacent Tooth Position	Measurement Error (in degrees) [Impacted | Control]	% Measurement Error of Adjacent Tooth Position [Impacted | Control]
1	Lateral Incisor Tip	2.9 | 0.4	18.1 | 4.9
	Lateral Incisor Torque	3.1 | 2.7	4.2 | 4.0
	Lateral Incisor Rotation	2.3 | 2.9	4.7 | 5.2
	First Premolar Tip	1.8 | 3.5	1.9 | 3.8
	First Premolar Torque	2.9 | 1.9	3.0 | 2.0
	First Premolar Rotation	1.9 | 1.7	2.5 | 2.3
2	Lateral Incisor Tip	3.3 | 0.7	15.1 | 7.5
	Lateral Incisor Torque	3.6 | 2.3	4.8 | 3.5
	Lateral Incisor Rotation	3.3 | 3.1	8.1 | 6.4
	First Premolar Tip	2.1 | 2.5	2.4 | 3.1
	First Premolar Torque	1.4 | 3.6	1.6 | 4.1
	First Premolar Rotation	2.9 | 1.3	3.5 | 1.9
3	Lateral Incisor Tip	2.4 | 4.4	17.5 | 45.8
	Lateral Incisor Torque	4.1 | 3.1	5.2 | 4.9
	Lateral Incisor Rotation	1.1 | 1.1	1.4 | 1.0
	First Premolar Tip	1.3 | 2.0	1.3 | 2.2
	First Premolar Torque	0.2 | 3.7	0.2 | 3.9
	First Premolar Rotation	0.5 | 1.2	0.5 | 1.9
4	Lateral Incisor Tip	1.7 | 1.4	14.3 | 14.5
	Lateral Incisor Torque	2.1 | 1.3	2.9 | 2.3
	Lateral Incisor Rotation	1.1 | 1.7	2.1 | 3.0
	First Premolar Tip	1.9 | 3.1	2.0 | 3.4
	First Premolar Torque	0.5 | 3.7	0.6 | 3.8
	First Premolar Rotation	0.8 | 1.9	0.1 | 2.4
5	Lateral Incisor Tip	2.7 | 1.7	14.5 | 14.2
	Lateral Incisor Torque	3.0 | 1.4	4.3 | 2.1
	Lateral Incisor Rotation	1.4 | 1.2	2.3 | 1.9
	First Premolar Tip	2.1 | 0.9	2.7 | 0.9
	First Premolar Torque	3.0 | 2.1	3.1 | 2.2
	First Premolar Rotation	2.9 | 3.7	3.2 | 5.2

6	Lateral Incisor Tip	0.7 | 3.3	7.7 | 36.2
	Lateral Incisor Torque	0.7 | 2.9	0.8 | 3.7
	Lateral Incisor Rotation	1.7 | 2.3	5.9 | 7.0
	First Premolar Tip	2.6 | 1.9	3.0 | 2.0
	First Premolar Torque	2.4 | 2.7	2.6 | 3.5
	First Premolar Rotation	2.5 | 1.0	3.2 | 1.2
7	Lateral Incisor Tip	0.9 | 0.9	4.1 | 7.6
	Lateral Incisor Torque	1.8 | 2.8	2.3 | 4.1
	Lateral Incisor Rotation	0.7 | 2.1	2.5 | 3.8
	First Premolar Tip	3.9 | 1.2	4.5 | 1.3
	First Premolar Torque	1.9 | 2.6	2.2 | 2.5
	First Premolar Rotation	0.9 | 3.1	1.4 | 4.0
8	Lateral Incisor Tip	1.8 | 1.3	12.3 | 7.8
	Lateral Incisor Torque	3.6 | 1.0	3.5 | 1.2
	Lateral Incisor Rotation	2.3 | 1.6	7.4 | 2.4
	First Premolar Tip	1.7 | 1.3	1.8 | 1.3
	First Premolar Torque	2.7 | 5.4	2.8 | 5.9
	First Premolar Rotation	2.3 | 0.5	3.0 | 0.6
9	Lateral Incisor Tip	1.3 | 2.4	7.9 | 18.2
	Lateral Incisor Torque	2.1 | 1.7	2.9 | 2.5
	Lateral Incisor Rotation	2.5 | 0.3	5.9 | 0.9
	First Premolar Tip	2.1 | 3.2	2.6 | 3.8
	First Premolar Torque	1.4 | 2.0	1.4 | 2.2
	First Premolar Rotation	0.8 | 0.3	1.0 | 0.4
10	Lateral Incisor Tip	1.8 | 0.9	22.4 | 9.5
	Lateral Incisor Torque	3.4 | 0.9	3.6 | 1.0
	Lateral Incisor Rotation	1.9 | 2.1	4.7 | 5.7
	First Premolar Tip	1.2 | 7.6	1.2 | 8.4
	First Premolar Torque	0.9 | 2.5	1.0 | 2.6
	First Premolar Rotation	0.2 | 3.9	0.2 | 5.3

Table C.7 – Raw collected data of dental follicle volume for inter-rater reliability

Patient	Dental Follicle Volume Week 1 ML	Dental Follicle Volume Week 2 ML	Dental Follicle Volume Week 1 LN	Dental Follicle Volume Week 2 LN	Dental Follicle Volume Week 1 ED	Dental Follicle Volume Week 2 ED
1	290.3	275.4	302.3	295.4	290.1	314.6
2	459.6	474.2	455.5	448.2	549.9	523.8
3	282.5	290.1	287.3	305.3	328.4	324.7
4	331.2	340.4	416.5	399.2	333.2	350.2
5	251.2	240.8	265.4	274.3	276.3	246.6
6	344.7	330.2	413.8	383.2	313.3	303.2
7	260.4	275.2	270.4	279.3	282.7	252.1

Table C.8 – Measurement error and percent measurement error of dental follicle volume for inter-rater reliability

Patient	Investigator	Measurement Error (in mm^3) of Dental Follicle Volume	% Measurement Error of Dental Follicle Volume
1	ML	14.9	5.3
	LN	6.9	2.3
	ED	24.5	8.1
2	ML	14.6	3.1
	LN	7.3	1.6
	ED	26.1	4.9
3	ML	7.6	2.7
	LN	18.0	6.1
	ED	3.7	1.1
4	ML	9.2	2.7
	LN	17.3	4.2
	ED	17.0	5.0
5	ML	10.4	4.2
	LN	8.9	3.3
	ED	29.7	11.4
6	ML	14.5	4.3
	LN	30.6	7.7
	ED	10.1	3.3
7	ML	14.8	5.5
	LN	8.9	3.2
	ED	30.6	11.4

Figure C.3 – Results of the multivariant regression analysis on IBM SPSS Statistics

Multivariate Tests for the Lateral Incisor Sample[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.272	5.611[b]	3.000	45.000	.002
	Wilks' Lambda	.728	5.611[b]	3.000	45.000	.002
	Hotelling's Trace	.374	5.611[b]	3.000	45.000	.002
	Roy's Largest Root	.374	5.611[b]	3.000	45.000	.002
DentalFollicleVolume	Pillai's Trace	.050	.784[b]	3.000	45.000	.509
	Wilks' Lambda	.950	.784[b]	3.000	45.000	.509
	Hotelling's Trace	.052	.784[b]	3.000	45.000	.509
	Roy's Largest Root	.052	.784[b]	3.000	45.000	.509

a. Design: Intercept + DentalFollicleVolume

b. Exact statistic

Multivariate Tests for Lateral Incisor Sample without Outliers[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.360	8.073[b]	3.000	43.000	<.001
	Wilks' Lambda	.640	8.073[b]	3.000	43.000	<.001
	Hotelling's Trace	.563	8.073[b]	3.000	43.000	<.001
	Roy's Largest Root	.563	8.073[b]	3.000	43.000	<.001
DentalFollicleVolume	Pillai's Trace	.130	2.135[b]	3.000	43.000	.110
	Wilks' Lambda	.870	2.135[b]	3.000	43.000	.110
	Hotelling's Trace	.149	2.135[b]	3.000	43.000	.110
	Roy's Largest Root	.149	2.135[b]	3.000	43.000	.110

a. Design: Intercept + DentalFollicleVolume

b. Exact statistic

Multivariate Tests for the First Premolar Sample[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.018	.118[b]	3.000	19.000	.948
	Wilks' Lambda	.982	.118[b]	3.000	19.000	.948
	Hotelling's Trace	.019	.118[b]	3.000	19.000	.948
	Roy's Largest Root	.019	.118[b]	3.000	19.000	.948
DentalFollicleVolume	Pillai's Trace	.049	.329[b]	3.000	19.000	.804
	Wilks' Lambda	.951	.329[b]	3.000	19.000	.804
	Hotelling's Trace	.052	.329[b]	3.000	19.000	.804
	Roy's Largest Root	.052	.329[b]	3.000	19.000	.804

a. Design: Intercept + DentalFollicleVolume

b. Exact statistic

Multivariate Tests for First Premolar Sample without Outliers[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.001	.008[b]	3.000	18.000	.999
	Wilks' Lambda	.999	.008[b]	3.000	18.000	.999
	Hotelling's Trace	.001	.008[b]	3.000	18.000	.999
	Roy's Largest Root	.001	.008[b]	3.000	18.000	.999
DentalFollicleVolume	Pillai's Trace	.033	.204[b]	3.000	18.000	.892
	Wilks' Lambda	.967	.204[b]	3.000	18.000	.892
	Hotelling's Trace	.034	.204[b]	3.000	18.000	.892
	Roy's Largest Root	.034	.204[b]	3.000	18.000	.892

a. Design: Intercept + DentalFollicleVolume

b. Exact statistic

Chapter 5

Discussion, Limitations & General Conclusions

5.1 Discussion

As there are technological advances in dentistry, there are new opportunities to explore aspects of human dentition that were not readily available in the past with traditional radiographic modalities. CBCT imaging has provided a 3D insight into impacted teeth that reduces uncertainties such as impacted tooth position and proximity to adjacent teeth. The purpose of this study is to assess how the volume of the dental follicle of the palatally impacted maxillary canine affects the relative position (tip, torque, and rotation) of the adjacent lateral incisor and first premolar. The potential of the hydraulic pressure created by the dental follicle content during tooth eruption could potentially displace the adjacent teeth. This is a unique perspective on the potential effects of the impacted maxillary canine and its associated dental follicle. If significant displacements were to be demonstrated, it could warrant early intervention to manage dental follicles to avoid certain malocclusion traits. This was performed by assessing previous CBCT records of patients with unilaterally palatally impacted maxillary canines with OxiriX DICOM Viewer. Given that unilateral palatally impacted maxillary canine are more prevalent than buccally impacted and bilateral canines, we decided to focus our attention on this population as it was easier to gain access to a larger sample and was more likely to appear in daily orthodontic practice. We were unable to fully assess the medical/dental records of the 49 patient records recruited for this thesis as the records dated from 2010 until now and was sourced from three other countries including Italy, Sweden, and Israel, which made it difficult to coordinate. The collected samples were separated into the lateral incisor and first premolar groups based on actual physical contact of the dental follicle to either or both adjacent teeth. To our knowledge, no studies have directly evaluated the dental follicle in this manner.

Previous studies have generally focused on the radiographic characteristics of the dental follicle and its association with root resorption in the adjacent teeth. Briefly mentioned in the study by Ericson and Bjerklin (2001), they mentioned that they believe the deviation in adjacent root position is most likely due to the eruptive force of the canine and not by the dental follicle itself. However, they also indicate that they cannot confirm if widened dental follicles during maxillary canine eruption increase the risk of adjacent incisor root displacement.[19] A year later (2002), in a CBCT study, the same authors focused on whether the dental follicle of the impacted maxillary canines causes root resorption of the neighboring lateral incisor based on the width, shape and proximity of the dental follicle. They concluded that there was a significant relationship to be found amongst those variables of the dental follicle; however, they did conclude that the dental follicle of the maxillary impacted canine does cause root resorption of the deciduous canine.[23] Chaushu et al. (2015) found that female patients (4.2 times) with enlarged dental follicles wider than 2 mm (8.3 times) and normal lateral incisors (5.8 times) were more at risk for severe incisor root resorption.[29] Dagsuyu et al. (2017) found that the largest statistically significant dental follicle size (3.51 mm +/- 1.19 mm) of maxillary impacted canines was found to be more common in mild resorption (up to half the dentin thickness) cases in the adjacent lateral incisors. Interestingly, the dental follicle size was smaller in moderate resorption (2.60 mm +/- 0.60 mm) and severe resorption (2.91 mm +/- 1.35 mm), where the resorption encroaches or perforates the pulp. However, they also concluded that they could not confirm that increased dental follicle widths correlate with an increased risk of resorption on the adjacent lateral incisor.[30] It is important to note that each of these studies assessed the width of the dental follicle measured as the largest distance from the crown of the maxillary canine to the periphery of the dental follicle on axial CBCT slices. Our study, focusing on overall dental follicle volume, suggested that the volume of the dental follicle of the palatally impacted maxillary canine does not affect the relative position of the adjacent lateral incisor and first premolar.

Intra-rater reliability of the principal investigator (ML) was excellent for the volumetric measurements of the dental follicle and the angular measurements of the adjacent teeth with ICC values above 0.75 at the minimum (Section 4.1.1). A reasonable variation in the dental follicle volume measurement error was seen, ranging from 2.7% to 9.7% in comparison to the angular measurements of the lateral incisor and first premolar that was also reasonable except for the lateral incisor tip on the impacted canine side that ranged from 4.1% to 22.4%. This larger variation in the lateral incisor tip is most likely due to the intersect of the angular reference point, where the more acute the mesiodistal tip of the lateral incisor, the further out the angle was established on the vertical reference plane. This created some subjectivity when aligning the angle with the long axis of the lateral incisor. Nevertheless, inter-rater reliability between the three investigators (ML, LN, and ED) was good for the volumetric measurement of the dental follicle, with the ICC value above 0.75 (Section 4.1.2).

Reliability testing of the angular measurements of the adjacent teeth between the investigators was not done as the method was adapted from the study by Dekel et al. in 2021.[7] The ICC for their study showed excellent reliability for the angular measurements, and two of the primary investigators of that study are currently involved with this thesis.[7] The method of measuring the dental follicle volume was developed and discussed numerous times to ensure that all three investigators were coordinated for the reliability testing. One of the critical steps was ensuring that the crown of the tooth was excluded from the region of interest segmentation, which eliminated hyperinflated volumetric measurements and provided a "true" volume of the dental follicle.

The results of the lateral incisor sample suggest that there is not enough evidence ($p = 0.509$ with the outliers and $p = 0.110$ without the outliers) to reject the null hypothesis; therefore, the differences are not statistically significant. In other words, there is no difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent lateral incisor between the impacted and control sides when comparing the volume of the dental follicle as it contacts the lateral incisor. Based on the tip, torque, and rotation angular of the adjacent lateral incisor, it appears that the data was consistent with the findings of Dekel et al. (2021), as the lateral incisor had exhibited an overall trending distal crown tip/mesial root tip, palatal crown torque/buccal root torque, and mesiobuccal rotation on the palatally impacted maxillary canine in comparison to the control side without considering the dental follicle.[7] This was also consistent with Liuk et al. (2013), who found that the adjacent lateral incisor was retroclined and mesiobuccally rotated concerning the palatally impacted maxillary canine.[18] However, their findings did not show the mesial root tip that was seen in our samples or the samples of Dekel et al. (2021).[18]

The results of the first premolar sample suggest that there is not enough evidence ($p = 0.804$ with the outliers and $p = 0.892$ without the outliers) to reject the null hypothesis; therefore, the differences are not statistically significant. In other words, there is no difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent first premolar between the impacted and control sides when comparing the volume of the dental follicle as it contacts the first premolar. No general trend was seen in the tip, torque, or rotation when comparing the impacted and control sides without considering the dental follicle. This was not consistent with Dekel et al. (2021), who found that the palatally impacted maxillary canine had caused a mesiobuccal rotation and buccal root torque of the first premolar dependent on the degree of impaction relative to the first premolar.[7]

Our samples showcased clear contact of the dental follicle with the lateral incisor and/or first premolar, without the physical contact of the crown, which allowed us to assess any involvement of the dental follicle and its associated volume on root displacements. Given that our results suggested no statistical significance in the difference of the relative position of the adjacent lateral incisor and first premolar in relation to the dental follicle volume of the impacted canine compared to the control side, our findings may suggest that the physical contact of the crown of the canine with the neighboring root may be a crucial factor in tooth displacement. As the dental follicle expands, it is noted that the vector of expansion moves towards the path of least resistance. It was seen that the follicle would enlarge towards the palate, but more often asymmetrically towards the interradicular regions between the adjacent lateral incisor and first premolar. Another factor to consider is if the impacted canine was currently undergoing eruption or was stagnant in position as the propulsive eruptive mechanism could exert pressure to displace the adjacent teeth. As with most biological/physiological events in the human body these are of a multifactorial origin. Expecting that a single factor would be the main culprit is not necessarily fair. Nevertheless, the hydraulic pressure hypothesis was not fully supported.

With future research, it would be interesting to consider analyzing the dental follicles that fall into the extremely large ranges of volumetric measurements that were seen in this thesis. Perhaps there is a threshold volume that must be exceeded in order to create a notable effect on the adjacent teeth positions. Only four out of the 49 patient CBCT records gathered for this thesis had a dental follicle volume that surpassed 450 mm^3. The dental follicle measured from the widest portion spanning from the crown of the maxillary canine to the periphery of the dental follicle measured 2.80 mm on average (based on the axial view of the CBCT), which is within the normal range and negates any suspicion of pathology (ie: dentigerous cyst).

Another scenario that could be further analyzed includes the angular position of the adjacent central incisor as this was not considered in the present thesis. In previous studies, it has been shown that the maxillary central incisor that is ipsilateral to the maxillary impacted canine is at risk of root resorption to a lesser extent to that of the adjacent maxillary lateral incisor. Ericson et al. (2000) found that 38% of maxillary lateral incisors and 9% of maxillary central incisors had exhibited root resorption that were in direct contact with the ectopically erupted maxillary canine for their sample.[31] Chaushu et al. (2015) also noted that out of their 96 severely resorbed (at least 1/3 of the root resorbed) maxillary incisor sample, 69 lateral incisors and 27 central incisors were resorbed (2.5:1 ratio).[29] With these findings, it would be interesting to see if there are any pathognomonic changes to angular position of the central incisor in relation to the maxillary impacted canine.

5.2 Limitations

Many CBCT-related factors play a role in the quality of the image generated, including voxel size, its inherent image artifacts, tube current and voltage, fields of view and imaging software. CBCT scans are generally acquired at four voxel sizes, including super high (0.125 mm), high (0.2 mm), medium (0.3 mm) and low (0.4 mm) resolutions. In clinical settings, a voxel size of 0.3 mm appears appropriate enough to generate a resolution suitable for a diagnostic aid and treatment planning tool. Higher resolutions are generally reserved for research and academic purposes. Voxel size significantly affects distinguishing structures and demarcating boundaries amongst structures, which is conceptually referred to as contrast resolution – the ability to discern two adjacent objects based on their grey values; and spatial resolution – the minimum distance needed to distinguish two different objects. These parameters can be improved by increasing tube output and exposure time; however, the ALARA (As Low As Reasonably Achieved) principle, as recommended by the ADA and FDA, should be followed to ensure patient safety, where the benefits and risks must be weighed against each other.[32,33] For the samples used in the thesis, voxel sizes of 0.25 mm – 0.4 mm were used, which may not be accurate or precise enough to capture the details of the dental follicle and surrounding structures. With smaller voxel sizes, it may provide further detail to enhance the segmentation process and rule out any possible subjectivity associated with the dental follicle.

All three investigators experienced difficulty discerning the borders of the dental follicle on the CBCT slices as they were not as defined as how a tooth or other high-density structure would appear at this resolution and tended to blend into the surrounding structures. The investigators had a general sense of subjectivity as the region of interest was traced for the volumetric rendering. This was evident during the methodology development for the volumetric measurements of the dental follicle. Initially, an automated segmentation was attempted; however, the seed voxels could not properly capture the surrounding voxels and all other voxels within a specific grey value range. In conjunction with ill-defined borders and the soft tissue radiodensity of the dental follicle, the resultant segmentation would leak into the surrounding structures, such as the trabeculae of the alveolar bone or even the oral cavity when nearby. Implementing a semi-automated segmentation process with manual refinement would have been advantageous as it is shown to have the best intra-observer and inter-observer reliability according to Forst et al. (2014), who focused on measuring the volume of the maxillary first molar via manual semi-automated and automated segmentation.[15] Based on a study by Liu et al. (2010), they noted that there is subjectivity between different observers when measuring the volume of the dentition in-vivo (in their case, 24 bicuspids) utilizing CBCT software.[16] When the authors compared the in-vivo CBCT results against the physical volumetric values of the bicuspids using the water displacement technique, one observer's measurements were larger, and the other observer's measurements were smaller, ranging from 2.65% +/- 6.75% and -4.13% +/- 2.65%, respectively.[16] This is consistent with a study done by Sang et al. (2016), who measured the volume of 50 teeth using two different CBCT machines (Newtom VG and VATECH DCTPRO) with two different voxel sizes (0.15 mm and 0.30 mm).[34] Their results show high volumetric accuracy as the Newtom VG 0.15 mm group, Newtom VG 0.30 mm group, and the VATECH DCTPRO 0.30 mm group had deviation of -5.4% +/- 2.8%, -4.5% +/- 3.4%, and -4.8% +/- 5.1%, respectively.[34] This suggests that the observer's perception of the structure of interest during the segmentation process can be quite subjective and may not accurately detect the actual volume of the dental follicle for this thesis. These values are within the angular and volumetric measurement range found in this thesis's data.

An essential factor of particular interest that influences the spatial resolution of CBCT images is known as the partial volume effect, where objects or boundaries of differing densities (such as hard tissue and soft tissue structures) are less than the size of the voxel (the smallest element of a 3D image), the neighboring densities are averaged and displayed at that junction. This can lead to an artificial increase or decrease in the resultant volume depending on the structure of interest, which is crucial in our study as the dental follicle of the impacted canines is adjacent to radiodense structures, such as the enamel of the maxillary canine crown and the bone of the maxillary alveolus. This effect was observed in the study by Ye et al. (2012), who looked at the accuracy of in-vitro tooth volumetric measurements from CBCT images.[35,36] In *Figure 5.1*, two images scanned with 0.125 mm voxels and 0.4 mm voxels can be seen, illustrating the difference in image quality and the partial volume effect.

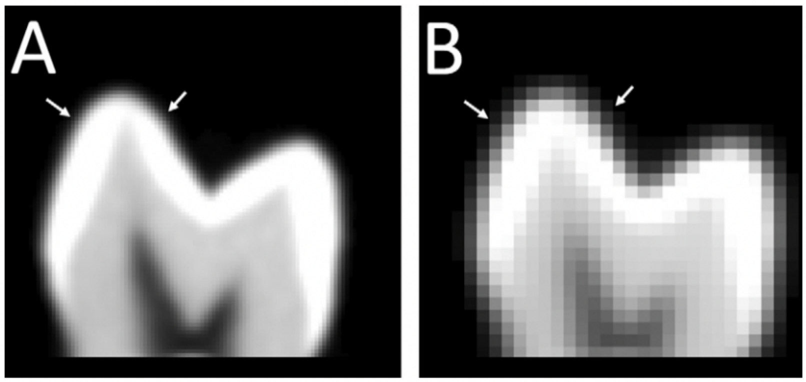


Figure 5.1 – Image illustrating difference in image quality and partial volume effect (Figure 4 from Ye et al.)[35]

The importance of voxel size is further illustrated by Coutsiers Morell et al. (2022), who compared the difference in volumetric measurement of 12 extracted teeth using 0.25 mm and 0.30 mm CBCT scans against 0.06 mm micro-CT scans.[36] They concluded that there was a consistent artificial increase in volume ranging between 15.2% (81.6 mm^3) to 28.1% (152.8 mm^3) in the CBCT scans compared to the micro-CT scans. They attributed this inflation in volumetric measurements to the voxel size, the partial-volume effect, noise, field of view size and/or segmentation subjectivity.[37]

Another factor influencing the spatial resolution of CBCT images is scatter caused by unwanted photons diffracting from their original path after interacting with matter, also known as noise. This noise can affect the density values of different tissues, inflating volumetric measurements. CBCT scans are more prone to scatter than medical CTs and are reduced by decreasing the field of view to capture the ROI.[32] In our study, a field of view capturing the maxilla was required to use the palatal plane as the reference point for many of our angular measurements of the adjacent teeth.

Patient movement is another variable that needs to be considered when considering image quality during CBCT acquisition. Studies have noted that simple things such as breathing could create enough motion that may distort the accuracy and quality of the image. This is unavoidable as the CBCTs taken for this thesis ranged anywhere from 2 – 8.9 seconds, a large enough window for the patient to move during the CBCT acquisition. However, all scans were by experienced technicians, aiming to avoid such acquisition errors.

5.3 General Conclusions

Diagnosing and treating impacted maxillary canines are challenges that orthodontists regularly face in private and academic clinical settings. With the technological advancement of radiographic imaging techniques, we can gain in-depth insight into dentition that was not readily available in the past with traditional modalities. Concerning this thesis and its considered limitations, the following conclusions were drawn:

- The protocol implemented for manual segmentation for the volumetric rendering of the dental follicle of the impacted canine possessed excellent intra-rater and good inter-rater reliability; however, subjectivity plays a significant role when assessing and tracing the dental follicle on CBCT images. The protocol implemented for manual angular measurement of the adjacent lateral incisor and first premolar possessed good to excellent intra-rater reliability.
- There is no statistical difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent lateral incisor between the impacted and control maxillary canine sides when comparing the volume of the dental follicle as it contacts the lateral incisor.
- There is no statistical difference in the change of mesiodistal tip, buccolingual torque, and mesiodistal rotation of the adjacent first premolar between the impacted and control maxillary canine sides when comparing the volume of the dental follicle as it contacts the first premolar. However, it is important to note that the sample size of the first premolar is notably smaller than the sample size required for this thesis.

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