MANDIBULAR DENTAL CHANGES FOLLOWING SERIAL AND LATE EXTRACTION OF MANDIBULAR SECOND PREMOLARS

by

Robert Mintenko

D.M.D., University of Saskatchewan, 2013

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2018

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, a thesis/dissertation entitled:

Dental Changes Following Serial and Late Extraction of Mandibular Second Premolars

submitted by Robert Mintenko in partial fulfillment of the requirements

the degree of Master of Science

in Craniofacial Science

Examining Committee:

Dr. David Kennedy, Faculty of Dentistry

Supervisor

Dr. Edwin Yen, Faculty of Dentistry

Supervisory Committee Member

Dr. Jolanta Aleksejuniene, Faculty of Dentistry

Supervisory Committee Member

Dr. David MacDonald, Faculty of Dentistry

Additional Examiner

Additional Supervisory Committee Members:

Dr. Alan Hannam, Faculty of Dentistry

Supervisory Committee Member

Abstract

Introduction: 15% of the general population are affected by severe dental crowding where conventional orthodontic treatment involves permanent dentition extractions. An alternative treatment method involves serial extraction in the mixed dentition. There is currently limited research on second premolar serial extraction.

Objectives: To determine the changes in occlusal curves and dental tipping that occur from mandibular second premolar serial extraction and early extraction of deciduous mandibular second molars with missing mandibular second premolars.

Methods: Records were collected from 85 subjects at 3 timepoints: T0, baseline for the control and serial extraction patients; T1, after extraction and physiologic drift but prior to orthodontic treatment for serial extraction patients, and pre-treatment for the late premolar extraction patients; and T2, after comprehensive orthodontic treatment. Three occlusal curves were measured on digitized mandibular casts by placing best fit spheres at specified landmarks. The long axes of the lower first molar, first premolar, canine and central incisor to the palatal plane were measured on digitized cephalometric radiographs to determine the direction and amount of tipping.

Results: At T0, there were no significant differences between groups. At T1, there was significant steepening of Monson's Sphere and the Curve of Wilson between early and late extraction groups. At T2, the differences in Monson's sphere and the Curve of Wilson were fully corrected. At T1, there were significant differences in the tipping of lower 6's, 4's and 3's

between the early extraction groups compared to the late extraction and control groups. There was no difference in lower incisor tipping between any group. At T2, the differences in tipping were fully corrected.

Conclusions: Serial extraction of lower second premolars, or lower deciduous second molars when second premolars were missing, produced steeper occlusal curves and significant tipping of mandibular first molars, first premolars and canines after extraction and physiologic drift (T1). The tipping of teeth and accentuated occlusal curves of Monson's sphere and the Curve of Wilson were fully corrected following comprehensive fixed orthodontic treatment (T2). Serial extractions involving lower second premolars or lower deciduous second molars did not cause any significant lingual tipping of lower incisors following physiologic drift.

Lay Summary

Approximately 15% of the general population are affected by severe dental crowding which require patients to have extractions, usually four premolars, as part of their orthodontic treatment. An orthodontist can either extract these teeth once all the adult teeth have erupted or while there are still baby teeth present. This study evaluated the changes in the teeth when a patient had lower second premolars or lower second baby molars extracted earlier on when there were still baby teeth present (serial extraction). The findings of the study included tipping of adjacent teeth and a deeper curve of the lower teeth after early extractions. However, these minor side effects were fully corrected after patients finished orthodontic treatment with braces. Additionally, the study showed that even with early extractions there was no difference in the amount the lower front teeth tipped back compared to those who did not have teeth extracted.

Preface

The research topic of this project was suggested by Dr. David Kennedy. There was a similar previous study completed at UBC by Dr. Esther Feldman in 2014 which involved serial extraction of mandibular first premolars and the resulting changes in occlusal curves and dental tipping. Part of the intention of this study was to be able to compare the differences found between serial extraction of mandibular first premolars versus mandibular second premolars.

The data was collected by Rob Mintenko, with data analysis done by Rob Mintenko. Statistical analysis was completed with the guidance of Dr. Jolanta Aleksejuniene. Rob Mintenko prepared the manuscript with content editing by Dr. David Kennedy, Dr. Jolanta Aleksejuniene, Dr. Ed Yen and Dr. Alan Hannam.

This research was approved by the Research Ethics Board at the University of British Columbia, ethics certificate number H16-01763.

Table of Contents

Abstract ..... **iii**

Lay Summary ..... **v**

Preface ..... **vi**

Table of Contents ..... **vii**

List of Tables ..... **ix**

List of Figures ..... **x**

List of Abbreviations ..... **xi**

Acknowledgements ..... **xii**

Dedication ..... **xiii**

Chapter 1: Introduction **1**

1.1 Analysis of the dental changes following serial extractions 3

1.2 Alternative serial extraction patterns 4

1.3 Related studies analyzing effects of first and second premolar serial extractions 9

1.4 Objectives 11

1.4.1 Null hypotheses 12

1.4.2 Study hypotheses 13

Chapter 2: Materials and Methods **14**

2.1 Participants 14

2.1.1 Power calculation 14

2.1.2 Inclusion and exclusion criteria 14

2.1.3 Age matching protocols 16

2.2 Methods 17

2.2.1 Time Points of Measurements 20

2.2.2 Measuring Dental Tipping 21

2.2.3 Measuring Occlusal Curves 23

2.3 Statistical Analysis 25

Chapter 3: Results 26

3.1 Occlusal Curves 28

3.2 Dental Tipping 34

Chapter 4: Discussion 41

4.1 General Discussion 41

4.2 Limitations of the Study 46

4.3 Future Directions 51

Chapter 5: Conclusions 53

References 54

List of Tables

Table 1: Summary of Ages at T0, T1 and T2 27

Table 2: One-way ANOVA of age between groups at T0, T1 and T2 27

Table 3: Summary of Occlusal Curve Results 28

Table 4: Summary of Changes in Occlusal Curves from T0 to T1 and T1 to T2 28

Table 5: Multiple Comparisons Bonferroni Test of Differences in Occlusal Curves 30

Table 6: Summary of Tooth Tipping Results 34

Table 7: Summary of Changes in Tooth Angulation 34

Table 8: Multiple Comparisons Bonferroni Test of Differences in the Tipping of Teeth 36

List of Figures

Figure 1: Example of a treatment summary sheet completed for every patient 18

Figure 2: A flowchart of the data collection process 19

Figure 3: Cephalometric film with reference plane at palatal plane (Yoshihara 2000)..... 22

Figure 4: 3D Renderings of the Spheres Representing Occlusal Curves..... 24

Figure 5: Box plot of Monson's Spheres between all groups at T0, T1 and T2..... 31

Figure 6: Box plot of Curve of Wilson spheres between all groups at T0, T1 and T2..... 32

Figure 7: Box plot of Curve of Spee spheres between all groups at T0, T1 and T2..... 33

Figure 8: Box plot of lower first molar tipping between all groups at T0, T1 and T2 37

Figure 9: Box plot of lower first premolar tipping between all groups at T0, T1 and T2 38

Figure 10: Box plot of lower canine tipping between all groups at T0, T1 and T2..... 39

Figure 11: Box plot of lower central incisor tipping between all groups at T0, T1 and T2 40

List of Abbreviations

AAO: American Association of Orthodontists

ABO: American Board of Orthodontics

COS: Curve of Spee

COW: Curve of Wilson

Lower E's: Deciduous mandibular second molars

Early ext 5's: Early extraction of mandibular second premolars

Early ext E's: Early extraction of deciduous mandibular second molars

Late ext 5's: Late extraction of mandibular second premolars

Lower 1's: Mandibular central incisors

Lower 3's: Mandibular canines

Lower 4's: Mandibular first premolars

Lower 5's: Mandibular second premolars

Lower 6's: Mandibular first molars

M: Monson's sphere

MP: Mandibular plane (gonion to menton)

OHSU: Oregon Health Sciences University

PAR: Peer assessment rating

SN: Sella-nasion plane (sella to nasion)

Std Dev: Standard deviation

UBC: University of British Columbia

Acknowledgements

I would like to express my sincerest gratitude to Dr. David Kennedy who has served not only as my research supervisor, but also has guided my overall development as an orthodontist from both a clinical and research perspective. The amount of time and energy he has placed into bettering our orthodontic program at UBC along with supervising my specific research project cannot be understated.

I also want to acknowledge all the hard work and encouragement from my committee members in helping me complete this research project. A special thank you to Dr. Jolanta Aleksejuniene, who has given a considerable amount of her time in reviewing and advising me on the statistical analysis component of my research; and to Dr. Alan Hannam for meeting on numerous occasions to suggest and advise on the many possible methodologies available for my project, and to Dr. Ed Yen for providing feedback at every turn in helping me to stay focused.

I could not have completed this research project without the help of Molly Furlong, at the Pediatric Dental Group, who was extremely generous and helpful in finding several of the long-term records that were initially unlocatable. The coordination from Oregon Health Sciences University librarian Meg Langford was instrumental in transferring digital copies of patient records from the AAO Legacy Collection that comprised my control group. The help from Angelica Laron at UBC in the scanning of patient models was also greatly appreciated.

The initial research idea and original master's thesis completed by Dr. Esther Feldman in 2014 helped pave the way for my similarly based research project. It is due to Dr. Feldman's research on this topic with Dr. Kennedy's guidance that my project came to be.

Lastly, I want to thank my wife, Daniela, for her support, patience and understanding throughout this research project and the completion of my orthodontic studies.

Dedication

This thesis is dedicated to Dr. David Kennedy for taking a chance on accepting me into this program, for teaching me the fundamentals of orthodontics, and for serving as my supervisor in guiding my research project. The development of the UBC orthodontic program is due to his endless contributions in making the program the best it can be. Thank you, Dr. Kennedy, for all your wisdom, guidance and support over the past three years.

Chapter 1: Introduction

In orthodontics, a long running treatment debate is whether a tooth size arch length discrepancy should be treated with a non-extraction or an extraction approach (Vaden, Dale, & Klontz, 2011). When a patient presents with severe crowding in the full permanent dentition, extraction of four premolars is often indicated (Gianelly, 1994). In the mixed dentition, the orthodontist has the opportunity to employ different methods to resolve crowding such as leeway space management through disking or space maintainers, expansion, or serial extractions (Graber 1971; Gianelly 1994; Graber et al 2012; Proffit et al 2012). Serial extractions have been used as early as the mid-18th century, but became popularized during Tweed's philosophies in the 1950's (Ringenberg 1967; Brandt & Tweed 1967; Graber et al 2012; Feldman et al 2015).

The objective of serial extraction is to create space in the mixed dentition for the eruption and self-alignment of permanent teeth over basal bone, and to minimize the complexity of future permanent dentition orthodontic treatment (Kjellgren 1947; Hotz 1970; Little 1987; Wagner and Berg 2000; O'Shaughnessy et al 2011). Most patients who undergo serial extractions require full fixed orthodontic treatment in the permanent dentition. This corrects some of the negative sequelae from serial extractions, such as residual spacing and tipping, as well as any additional alignment issues that were not spontaneously resolved during the post extraction drift phase (Little 1987; Papandreas et al 1993; Boley 2002; O'Shaughnessy et al 2011).

The proposed benefits of serial extraction include self-alignment of teeth, permanent canines erupting into attached ginigiva, shorter active treatment time, and improved stability (Gianelly 1994; Wagner and Berg 2000; Boley 2002; O'Shaughnessy et al 2011). Some possible disadvantages of serial extractions include deepening the overbite, lingual tipping of incisors, distal tipping of lower canines, mesial tipping of the molars, creation of a diastema and increased

spacing, potential scar tissue build up in the area of the extraction sites and alteration of tongue function (Brandt & Tweed, 1967; Ringenberg 1967; Graber 1971; Feldman et al 2015).

Wagner and Berg found that treatment with serial extractions has a significant reduction in active treatment time of 0.9 years (approximately 11 months) but a longer overall treatment duration and increased total number of appointments (Wagner and Berg 2000). Results of final PAR scores of serial extraction and late premolar extraction groups showed in both groups the reduction in PAR scores was either improved or greatly improved, with a slightly greater average reduction in PAR scores seen in the serial extraction group (Wagner and Berg 2000). Wagner and Berg suggested that increased treatment duration and appointment numbers could potentially lead to loss of patient compliance and motivation; this should be taken into consideration when planning for serial extractions (Wagner and Berg 2000). One main cited advantage of serial extractions is a shorter active treatment (Wagner and Berg 2000; O'Shaughnessy et al 2011). O'Shaughnessy compared treatment times and outcomes for serial extraction and late first premolar extraction cases (O'Shaughnessy et al 2011). Despite the late premolar extraction group having a higher pretreatment PAR score, signifying a more difficult complexity prior to comprehensive treatment, there was no post treatment difference in PAR scores between the groups (O'Shaughnessy et al 2011). Both early and late extraction groups achieved clinically similar outcomes (O'Shaughnessy et al 2011). The serial extraction group had a significantly reduced average active treatment time of four to six months (O'Shaughnessy et al 2011). Despite this reduced active treatment time, the serial extraction group ended up with a significantly greater overall treatment length when the total number of visits, including examination and recall visits, were considered (O'Shaughnessy et al 2011).

1.1 Analysis of the dental changes following serial extractions

Yoshihara et al studied tipping of adjacent teeth and change in irregularity index following first premolar serial extraction (Yoshihara et al 2000). There was significant mesial tipping of the first permanent molars and distal tipping of incisors. The decrease in the irregularity index was greatest after primary canine extraction and less after first premolar extraction (Yoshihara et al 2000). Yoshihara did not study the effects of first premolar extraction on the occlusal curves, nor did he follow the sample through full fixed orthodontic treatment (Yoshihara et al 2000). Feldman's first premolar serial extraction sample was followed through comprehensive orthodontic treatment, where both changes in the tipping of teeth adjacent to extractions and occlusal curves were measured (Feldman et al 2015). Post extraction drift prior to full fixed orthodontic treatment, the permanent first molar tipped mesially, the lower incisors and canine tipped distally; there was a deepening of the curve of Spee and curve of Wilson (Feldman et al 2015). These findings concur with those of Yoshihara (Feldman et al 2015). Following comprehensive orthodontic treatment, the negative side effects from serial extractions were corrected (Feldman et al 2015). There was minimal incisor proclination to correct the lingual tipping post extraction, the canines uprighted to correct the distal tipping from extractions. There was significant molar uprighting associated with correcting the curve of Spee (Feldman et al 2015).

The curve of Spee is defined as the anatomic curve established by the occlusal alignment of the teeth, as projected onto the median plane and can be accentuated following serial extractions due to tipping of adjacent teeth and tooth drift (Prosthodontics 1994; Feldman et al 2015). Feldman et al reported on the effects of serial extractions on the curves of Spee and Wilson and Monson's sphere (Feldman et al 2015). Both curves deepened considerably after

serial extractions and before full fixed orthodontic treatment started (Feldman et al 2015). Simons and Joondeph highlighted the importance of the curve of Spee in orthodontic treatment by observing that malocclusions with an exaggerated curve of Spee are frequently associated with deep overbites (Simons and Joondeph, 1973). In Andrews' six keys of occlusion, a flat occlusal plane or a very mild curve of Spee was seen in the majority of normal and well treated occlusions; he suggested that this should be an end goal for orthodontic treatment (Andrews 1972).

The curve of Wilson is the buccal lingual inclination of mandibular molars, becoming more accentuated when the lingual cups are positioned in a more lingual direction (Prosthodontics 1994). A flat curve of Spee and upright curve of Wilson are considered cornerstones of high quality orthodontic treatment. It is important to further understand the effects that serial extractions, specifically of mandibular second premolars, have on these occlusal curves and on tooth tipping (Casko et al 1998; ABO Website 2016)

1.2 Alternative serial extraction patterns

Serial extractions are defined by Proffit as: the planned, sequential removal of primary and permanent teeth and involves extraction of the deciduous canines, followed by the first deciduous molars and finally the first premolars (Proffit et al 2012; Graber et al 2012). The classical serial extraction pattern is performed in three stages: 1) extraction of primary canines, 2) extraction of deciduous first molars to accelerate the eruption of the underlying first premolars, and 3) extraction of first premolars. This is followed by a period of physiologic drift before initiating full fixed orthodontic treatment (Boley 2002; Dugoni 2008; Proffit et al 2012). During this period of physiologic drift, or 'driftodontics', there is hopefully spontaneous

alignment of incisors and closure of extraction spaces, improvement in occlusal relationships and eruption of permanent canines into attached gingiva (Kjellgren 1947; Creekmore 1982; Alexander 2001).

Several scenarios may require modified serial extraction patterns where deciduous second molars and second premolars are extracted rather than deciduous first molars and first premolars (Joondeph and Reidel 1976). Second premolar serial extraction is indicated when there is impaction of the second premolars, due to arch length loss from premature loss of deciduous second molars and from inadequate space maintenance (Joondeph and Reidel 1976). Arch length loss may also be due to extensive unrestored proximal deciduous second molars caries (Joondeph and Reidel 1976). Early extraction of second premolars may be indicated when there is: 1) minimal anterior crowding and predominantly posterior crowding, 2) presence of a posterior arch length deficiency, and 3) absence of dental and facial protrusion (Joondeph and Reidel 1976).

Advantages of second premolar serial extractions compared to first premolars can then be listed as 1) more ideal root parallelism and marginal ridge contact, 2) limited lingual migration of mandibular anterior teeth, 3) minimal increase in the curve of Spee and overbite, 4) minimal flattening of the facial profile due to maintenance of lower incisor position, and 5) increased bodily drift of first and second molars which can aid in class II molar correction (Weber 1969; Joondeph and Reidel 1976). Weber reported mesial movement of the lower first molar with mandibular second premolar enucleation (Weber 1969). Two-fifths of the space closure resulted from molar movement while three-fifths of space closure resulted from distal movement of the lower canines (Weber 1969). Disadvantages associated with second premolar serial extractions include the requirement for an early extraction decision and delicate surgical intervention to preserve buccal and lingual bone (Joondeph and Reidel 1976).

Joondeph and McNeill highlighted a third indication for modifying the classical serial extraction approach which was congenitally missing mandibular second premolars (Joondeph and McNeill 1971). Extraction of deciduous second molars when the underlying second premolars are missing offer several benefits compared to treatment in the full permanent dentition. Advantages include avoiding the need for prosthetic replacement, reducing or eliminating the necessity for extensive orthodontic appliance therapy, and minimizing the undesirable postretention sequelae of establishing root parallelism and ideal contact between first molar and first premolar (Joondeph and McNeill 1971). With congenitally missing second premolars, treatment options include 1) extracting the deciduous second molar once all permanent teeth are present and space closure, 2) early extraction of the deciduous second molar, allowing for spontaneous space closure, with complete closure during comprehensive treatment, 3) retention of the deciduous second premolar with possibly necessary mesial-distal reduction and occlusal restoration provided the tooth is free of ankylosis, root resorption and extensive decay, and 4) prosthetic replacement of the deciduous second molar following extraction (Joondeph and McNeill 1971). Extraction decisions with congenitally missing second premolars are based on the same criteria as if a patient has a full complement of teeth; if there is a tooth size arch length discrepancy or presence of dental or facial protrusion then extraction should be considered (Joondeph and McNeill 1971; Kennedy 2016). When the malocclusion does not require extractions, then retention of the deciduous second molar or prosthetic replacement should be considered (Kennedy 2016). Lindqvist reported on the benefits of extracting deciduous second molars when the second premolar was absent; reporting that if the deciduous molar is extracted early, growth factors may be helpful in closing the extraction space (Lindqvist 1980). After investigating 101 children aged 5-12 years old who had early extraction of a deciduous

second molar when the second premolar was missing, Lindqvist found that four years post extraction there was on average 2mm of residual space in the lower and less than 1mm of residual space in the upper jaw (Lindqvist 1980). Lindqvist found that extraction after root development of neighbouring teeth was complete often led to closure of the extraction space by tipping so he recommended that if the second premolar is missing to seriously consider the treatment option of extracting the deciduous second molar at an earlier age when root development was still ongoing (Lindqvist 1980).

Guidelines by Kennedy reaffirm the treatment options proposed by Joondeph and McNeill, by keeping in mind four major principles involved with treating growing children who present with absent second premolars (Kennedy 2016). In a non-extraction approach, these principles include establishing the correct mesiodistal space for the missing tooth, establishing the proper occlusal height, and preserving the alveolar ridge (Kennedy 2016). Avoiding compromise of the lower incisor position is a key principle when an extraction approach is chosen and space closure is required (Kennedy 2016). In addition to the four treatment possibilities given by Joondeph and McNeill for treatment of a missing mandibular second premolar, Kennedy suggests a treatment alternative of a transplant in selected instances (Kennedy 2016). A transplant should be considered when there is crowding in one arch and missing teeth in the other; also, when a developing permanent tooth at approximately two-thirds root development is available to be transplanted to the site of a missing tooth (Kennedy 2016). Autogenous premolar transplants have a high long-term success rate of 79% at 26 years post-transplant, but may have risks of pulpal problems and ankylosis (Czochrowska 2002).

Kennedy offers a serial extraction alternative in class II patients, where there is early extraction of mandibular primary second molars and second premolars followed by physiologic

drift and spontaneous space closure (Kennedy 2016). This mesial drift of mandibular molars helps with class II molar correction (Weber 1969; Kennedy 2016). Instead of coincident early extraction in the maxilla, maxillary first premolars are extracted in the permanent dentition, at which time full fixed appliances can be placed and the extraction space utilized to retract the maxillary anterior teeth (Kennedy 2016).

Mamopoulou investigated space closure and occlusal changes in patients with normal occlusion and agenesis of the mandibular second premolars following extraction of mandibular second primary molars and maxillary second premolars (Mamopoulou et al 1996). The subjects were followed for four years (Mamopoulou et al 1996). Records included dental casts and lateral cephalograms to evaluate space closure, sagittal movements, rotational movements, tipping of first molars and first premolars and dental midline shift (Mamopoulou et al 1996). Most of the extraction space closed during the first year (55% in the maxilla, 46% in the mandible); at the end of the four-year follow-up period, 89% of the extraction space closed in the maxilla and 80% in the mandible, leaving a mean residual extraction space of 0.9 and 2.0 mm respectively (Mamopoulou et al 1996). In the mandible, the space closure occurred by mesial/rotational movements and tipping of first molars and distal movement and tipping of the first premolars (Mamopoulou et al 1996).

Extraction therapy had no impact on the overjet, overbite or incisor inclination (Mamopoulou et al 1996). Study weaknesses included a relatively small sample (11 total patients) and unilateral extraction patterns of some mandibular second primary molars (Mamopoulou et al 1996). The findings show that in subjects with normal occlusion and agenesis of mandibular second premolars, extraction of the mandibular second primary molars and compensatory extraction of the maxillary second premolars can be recommended as the

treatment of choice at the time when occlusion of the first premolars is secured (Mamopoulou et al 1996).

1.3 Related studies analyzing effects of first and second premolar serial extractions

The post-retention stability and relapse over 10 years in patients who had serial extraction of four first premolars were reported by Little (Little et al 1990). Of all, 73% of cases demonstrated clinically unsatisfactory mandibular alignment, while intercanine width and arch length decreased in all but one case (Little et al 1990). No difference was found between the serial extraction cases and matched controls that had four first premolars extracted in the full permanent dentition (Little et al 1990).

McReynolds and Little investigated the long term dental changes and stability following serial extraction of mandibular second premolars (McReynolds and Little 1991). An early extraction group (combined of those missing second premolars and those who had second premolars enucleated before eruption) was tested against a late premolar extraction group of second premolars. No difference in long-term stability between the two groups was found (McReynolds and Little 1991). Arch length and width decreased, and incisor irregularity increased throughout the post-retention period (McReynolds and Little 1991). Greater long-term stability was not achieved by second premolar serial extraction; however, such extractions may be indicated for periodontal, profile, and treatment time considerations (McReynolds and Little 1991). Serial extractions have been recommended to provide better long-term stability, while one study refutes those claims (McReynolds and Little 1991).

Haruki and Little studied long-term serial extraction patients who had fixed appliances placed immediately after extraction of first premolars in the mixed dentition for early incisor

alignment (Haruki and Little 1998). After 10 years post retention, the early treatment group had a more stable result with lower mandibular anterior irregularity index (3.09mm) compared to the late premolar extraction group that had a less stable long-term result and higher mandibular anterior irregularity index (4.15mm) (Haruki and Little 1998). By contrast, no fixed appliances were used in early treatment in the second premolar serial extraction group in the McReynolds study, where all patients had a minimum of one year of physiologic drift (McReynolds and Little 1991). Haruki's sample size was much larger with a total of 36 patients undergoing serial extractions versus 14 in the McReynolds serial extraction group. This suggests that early orthodontic anterior alignment of crowded first premolar extraction cases may be justified in order to reduce post-retention mandibular incisor irregularity (Haruki and Little 1998).

A systematic review investigated the most favorable time for initiating orthodontic treatment in patients with severe crowding (Lopes Filho et al 2015). Both early and late extraction cases had a similar effect on correction of crowding, while early treatment had two favorable secondary outcomes; namely less relapse and reduced active treatment time versus late treatment (Lopes Filho et al 2015). The levels of evidence were low to assert which protocol was superior (Lopes Filho et al 2015). This systematic review analysis only included 6 of 125 screened studies and based its conclusion that serial extraction groups had less relapse in only 2 of 6 studies that reported on relapse; these were the Haruki and Little study that showed there was a difference in stability and the Little study that showed there was no stability difference between early and late extractions (Little et al 1990; Haruki and Little 1998; Lopes Filho et al 2015). The Haruki study had the confounding factor of immediate placement of fixed appliances to align anterior teeth following extractions in the mixed dentition, compared to the Little study

which allowed for physiologic drift following extractions (Little et al 1990; Haruki and Little 1998; Lopes Filho et al 2015).

Kau studied the effectiveness of mixed dentition primary extractions in relieving lower anterior crowding and found a minimal reduction in lower incisor crowding as a result of lower primary canine extraction (occurrence of 1 in 4) (Kau et al 2004). However, arch perimeter decreased more in the extraction group leaving less space for the eruption of the lower permanent canines (Kau et al 2004).

Jacobson and Miller studied serial extraction effects comparing early extraction of a primary canine followed by a primary first molar to extraction of a primary first molar followed by a primary canine (Jacobson and Miller 2006). The extraction pattern difference had no impact on the treatment outcome. There was: 1) more counterclockwise rotation of the functional occlusal plane in the d-c group, 2) the maxillary incisors proclined more in the d-c group, 3) the maxillary incisor edge was more labial in the d-c group, and 4) treatment changes in position of the maxillary incisors along the functional occlusal plane were labial in the c-d group and lingual in the d-c group (Jacobson and Miller 2006).

1.4 Objectives

There is limited information on second premolar serial extractions especially in case-controlled trials. Much of the current evidence is based on case reports or expert opinions. One study evaluated tipping of adjacent teeth after second premolar serial extractions but it did not measure the occlusal curves (Mamopoulou et al 1996). Serial extractions are not a common treatment choice among most orthodontists due to a multitude of reasons (Joondeph and Reidel 1976; Wagner and Berg 2000; O'Shaughnessy et al 2011). The need to make an early extraction

decision, an increase in recall visits, and multiple coordinated appointments with a general or pediatric dentist for extractions may serve as deterrents to such treatment (Wagner and Berg 2000; O'Shaughnessy et al 2011). Since post-treatment results show similar results between early and late premolar extractions, orthodontists may not identify those cases that could benefit from serial extractions. Therefore, quantifiable data about second premolar serial extraction would be beneficial. It would help orthodontists be aware of possible serial extraction benefits, specifically when and why to consider second premolar serial extraction, or second deciduous molars if second premolars are absent, rather than to choose the classical first premolar serial extraction pattern.

1.4.1 Null hypotheses

The null hypotheses for the study were as follows:

I. There will be no difference between control or late extraction groups and serial extraction groups in terms of the post-extraction drift/pre-orthodontic treatment (T1) tipping of the first molar, first premolar, canine, and lower incisors or the curve of Spee, curve of Wilson and Monson's sphere.

II. There will be no difference between control or late extraction groups and serial extraction groups in terms of the post-orthodontic treatment (T2) tipping of the first molar, first premolar, canine, and lower incisors or the curve of Spee, curve of Wilson and Monson's sphere.

1.4.2 Study hypotheses

The hypotheses for the study are as follows:

I. Post-extraction drift/pre-orthodontic treatment of the serial extraction groups will show significant tipping of the first molar and first premolar, moderate tipping of the canine, minimal tipping of the lower incisors and a deepened curve of Spee, curve of Wilson and Monson's sphere.

II. Post-orthodontic treatment of the serial extraction groups will show full correction of the tooth tipping and occlusal curves where there is no difference in final results between serial extraction groups compared to late premolar extraction or controls.

Chapter 2: Materials and Methods

2.1 Participants

Patient records were collected from a Vancouver orthodontic practice that completed comprehensive orthodontic treatment between 1984 and 2006. Patients from this practice were retrospectively chosen to form the 3 treatment groups:

i) **25 patients:** Serial extraction of mandibular second premolars ('Early ext 5's'),

ii) **10 patients:** Serial extraction of primary mandibular second molars when the underlying second premolars were missing ('Early ext E's'),

iii) **25 patients:** Late extraction of mandibular second premolars ('Late ext 5's').

Patient records were collected from the Oregon Health Sciences University through the AAO Legacy Collection, from the years 1957-1976, to form the untreated control group:

iv) **25 records:** Untreated control group ('Control').

2.1.1 Power calculation

A power calculation was carried out to measure the sample size required for each group to achieve a desired power of .90. Using a value of .05 for alpha and a 2-sided test for comparing two independent samples, a sample size of 22 subjects per group was required for a power of .90. This sample size calculation supported the decision to use 25 subjects per test group.

2.1.2 Inclusion and exclusion criteria

Inclusion criteria for the Early Ext 5 group consisted of: serial extraction of both mandibular second premolars, phase of drift of at least 1 year in duration, 2 phase treatment,

comprehensive fixed appliance treatment and complete records (models and lateral cephalometric radiographs) available at all three time points.

Inclusion criteria for the Early Ext E group consisted of: congenitally missing both mandibular second premolars, serial extraction of both primary mandibular second molars, phase of drift of at least 1 year in duration, 2 phase treatment, comprehensive fixed appliance treatment and complete records (models and lateral cephalometric radiographs) available at all three time points.

Exclusion criteria for the both the Early Ext 5 group and the Early Ext E group consisted of: use of space maintenance appliances, missing mandibular teeth other than the congenitally missing mandibular second premolars, class III, craniofacial syndromes, partial treatment, and incomplete records.

Inclusion criteria for the Late Ext 5 group consisted of: extraction of both mandibular second premolars in the full permanent dentition, 1 phase treatment, comprehensive fixed appliance treatment and complete records (models and lateral cephalometric radiographs) available at time points T1 and T2. Exclusion criteria for the Late Ext 5 group consisted of: phase I treatment, use of space maintenance appliances, missing mandibular teeth, class III, craniofacial syndromes, partial treatment, and incomplete records.

Inclusion criteria for the Control group consisted of: no orthodontic treatment and complete records (models and lateral cephalometric radiographs) available at all three time points. Exclusion criteria for the Control group consisted of: previous orthodontic treatment, mandibular extractions, missing mandibular teeth, class III, craniofacial syndromes, and incomplete records.

2.1.3 Age matching protocols

Due to the rarity of cases treated with serial extraction of mandibular second premolars, that also had a minimum 1 year of physiologic drift and then comprehensive orthodontic treatment, there were only a total of 25 patients that had complete records available and met the inclusion criteria (‘Early ext 5’s’ group). It was then decided to select 25 patients from each of the late premolar extraction group (‘Late ext 5’s’) and the untreated control group. Each group had 70 and 107 total patient records respectively to choose a final selection of 25 patients each per group.

The method by which 25 patients were selected for the late premolar extraction group and untreated control group was to age match each group as close as possible to the average age of the 25 patients from the serial extraction group of mandibular second premolars. Chronological ages were readily available from patient records at each time point from both the private orthodontic practice and the long-term records from the OHSU AAO Legacy Collection and as such that is what was used to complete the age matching. Other possible age matching methods and their advantages and disadvantages are included further on in the discussion. The untreated control group was matched to the early extraction of second premolars group at T0 while the late premolar extraction group was matched to the early extraction of second premolars group at T1, since those late premolar extraction patients did not have records taken at a T0 timepoint (they presented for treatment in the full permanent dentition where extractions were done immediately prior to starting fixed orthodontic treatment).

The serial extraction group of deciduous mandibular second molars when the second premolars were missing (‘Early Ext E’s’) had a very limited number of possible patient records due to the low prevalence of bilateral congenitally missing second premolars that were also

treated with the above specified treatment protocol. In total there were only 10 patients that had complete records which could be included in this group. Despite the small number not meeting our power calculation we decided to include the group nonetheless as nowhere in our literature review could we find a similar cohort of patients having been reported on the effects in dental tipping and occlusal curves from early extraction of the deciduous second molars. No age matching was possible since we were limited to 10 patients only, however despite this there were no significant differences between ages among this group and the other three test groups at any of the three timepoints.

2.2 Methods

Treatment summary sheets of over 13,000 patient records were available for screening from the private orthodontic office of Dr. David Kennedy in Vancouver (see Figure 1).

RET MODEL # 2658 VOL _____ L NAME [redacted] F NAME [redacted]

B DATE 4 . 16 . 80 SEX F MO/YEAR BEGIN 4 . 90 MO/YEAR END 1 . 95

AP DENT	AP SKEL	PERM	TRANS	VERT
1. I	1. CR-CO shift	1. ALD mild	1. Seg. x-bite	1. Ant. open-bite
2. II.1	2. Mn retrog.	2. ALD severe	2. 1 tooth x-bite	2. Post. open-bite
3. II.1 sub	3. Mx retrog.	3. ALXS	3. CR-CO shift	3. Deep overbite
4. II.2	4. Mn prog.	4. Diastema	4. Mx midline off	4. Long face height
5. II.2 sub	5. Mx prog.	5. Tooth size discrep	5. Mn midline off	5. Short face height
6. III	6. Bimax protrusion	6. Rotation	6. Facial asymm.	6. Canting
7. Pseudo III	7. Bimax retrusion	7. Ectopic 3	7. Bilat. x-bite	7.
8. Ant. x-bite	8.	8. Ectopic 6	8.	8.
9. Other	9. Other	9. Other	9. Other	9. Other

EXTS	MN MISS	MX MISS	SURG	PERIO DX
1. Non Ext.	1. 1	1. 1	1. Mn	1. Local, bone loss
2. 4	2. 2	2. 2	2. Mx	2. Gen. bone loss
3. 5	3. 3	3. 3	3. Mx/MN	3. Gingivitis
4. 4 - 5	4. 4	4. 4	4. Segmental	4. Labial frenum
5. asymm.	5. 5	5. 5	5. Genioplasty	5. Recession
6. Mn incisor(s)	6. 6	6. 6	6. TMJ	6. Min. att. gingiva
7. MX incisor(s)	7. 7	7. 7	7.	7.
8. 8	8. 8	8. 8	8.	8.
9. Drift	9. Other	9. XT ▶ 4	9. Other	9. Other

PERIO TX	TOOTH AN	CF ANOM	HABITS	APPL.
1. Osseous surg.	1. Root resorp.	1. Unilateral cleft	1. Digit	1. Fixed ret.
2. Gingivectomy	2. Supernumerary	2. Bilateral cleft	2. Tongue	2. Removable ret.
3. Frenectomy	3. Ankylosed	3. JRA	3. Lip entrapment	3. Ret. w/pros. teeth
4. Graft	4. Transposed	4. Treacher Collins	4. Clenching	4. Positioner
5. Curettage	5. Impacted	5. Medical Involv.	5. Bruxism	5. L.A.
6. Expose teeth	6. Malformed	6. Condyle	6. Lip Biting	6. Elastics
7. CSF	7. Peg Lateral	7.	7.	7. Splint
8. Implant	8.	8.	8.	8. Pal. expander
9. Other	9. Other	9. Other	9. Other	9. Other

HG	FU APPLI	TX TIME	TMJ	Ret/Stor
1. CHG	1. Bionator to open	1. No Tx	1. Limited opening	1. Full Tx
2. CHG w/spur	2. Bionator to close	2. 1 phase	2. Pain	2. Partial Tx
3. PHG to 6	3. Bionator / HG	3. 2 phase	3. Dev. on opening	3. Phase I only
4. HG to ant.	4. Crib	4. Less than 12 mos.	4. Sounds	4. Phase I and Phase II
5. Combee	5. Herbst	5. 12-18	5. Displaced disc	5. Did not proceed after records
6. Protraction	6.	6. 19-24	6. Therapy	6. Transfer out during Tx
7. Chin cup	7.	7. Over 24	7.	7. Bail out
8.	8.	8. Mixed	8.	8.
9. Other	9. Other	9. Primary	9. Other	9.

Figure 1: Example of a treatment summary sheet completed for every patient

A diagrammatic summary of the hand searching data collection process through all the orthodontic records is described in figure 2 that provides the number of consecutively treated patient records screened as a possible match, total number of patients with model boxes and charts found, and total patients with a complete set of patient records chosen to be included in this study.

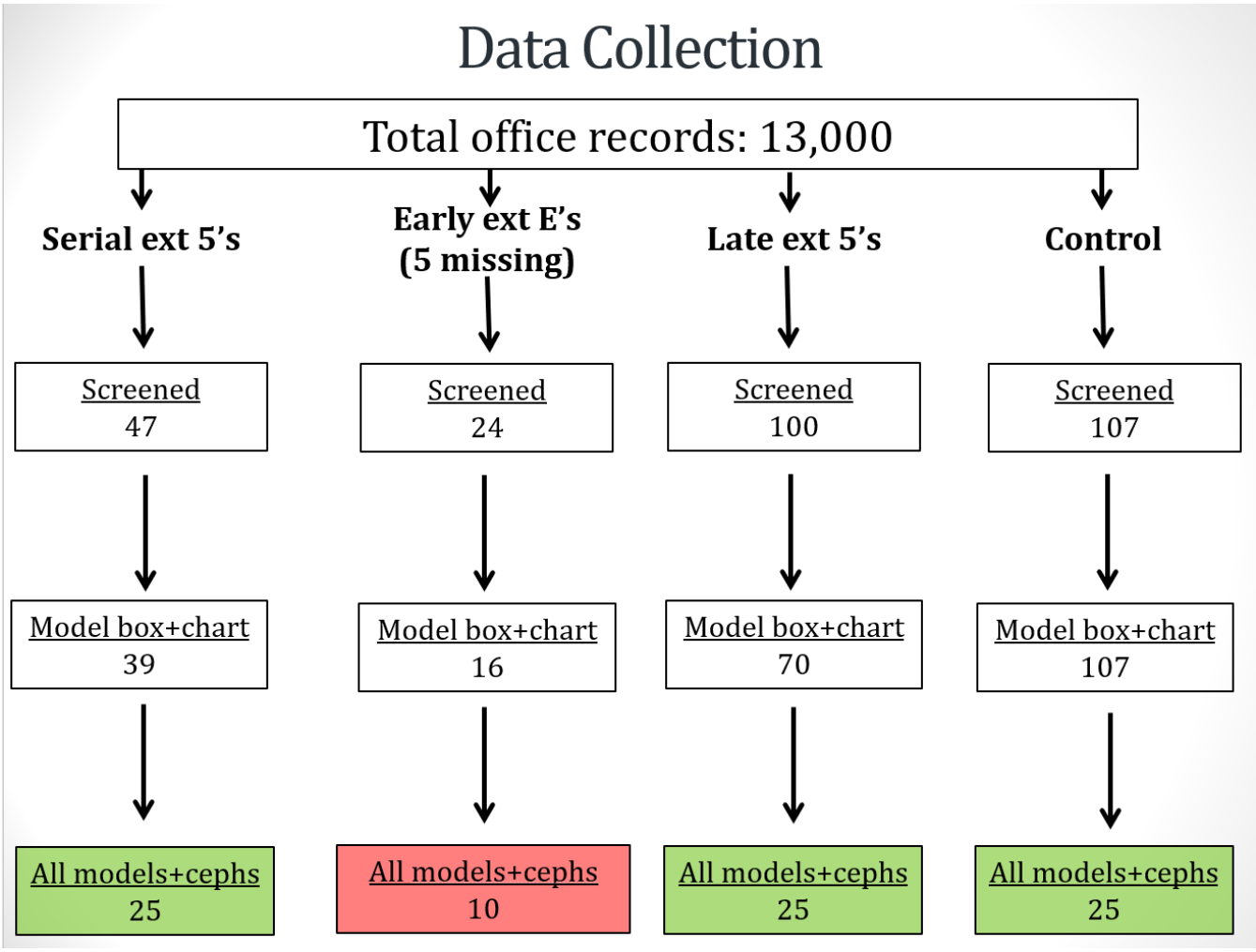

Figure 2: A flowchart of the data collection process

It should be noted that from the above total office records, it was rare to do serial extractions, rarer to do extract mandibular second premolars compared to first premolars, and even more rare to extract primary mandibular second molars when the underlying second premolars were congenitally missing. These factors alone contributed to a relatively low number of possible screened patients for inclusion in the serial extraction groups. From the total screened patients, several patients had to be excluded due to either a model box or chart that were missing. Due to the lengthy time period of storage of many of these records, some patient records had been previously destroyed at the time of data collection. Even once both the model box and chart were located, there were instances that there were incomplete records taken at our specified three different time points. Even if records had been taken at all time points, there were several models that had been damaged during storage, consequently unusable for our study purposes. These aforementioned reasons contributed to a lower final number of eligible patient records compared to the initial screened amount for possible inclusion.

2.2.1 Time Points of Measurements

Our research design included three overall points of time at which to measure all available records. The time points were as follows:

- T0: Baseline for the control and serial extraction patients,
- T1: After physiologic drift and prior to orthodontic treatment for the serial extraction patients, and pre-treatment for the late premolar extraction patients,
- T2: After comprehensive orthodontic treatment for the serial extraction and the late premolar extraction groups.

As previously mentioned, the control group was age matched against the average chronological age of the serial extraction of mandibular second premolars group at each time point to help provide a comparison group against subjects within the untreated control group.

2.2.2 Measuring Dental Tipping

From cephalometric radiographs, vertical lines drawn through the long axes of teeth of interest (first molars, first premolars, canines, central incisors), relative to the palatal plane which is a reliable and easily reproducible plane (Yoshihara et al 2000; Feldman et al 2015). Palatal plane (ANS-PNS) was the decided reference plane as it can be located precisely and is easily reproducible; it is located close to the areas under consideration and experiences minimal change over time compared to other possible reference planes (MP, SN, etc.) (Broadbent 1937, Brodie 1953). Palatal plane was also used by Yoshihara in 2000 and by Feldman in 2015, both noted there was no influence of growth changes at nasion, there was no influence of rotation of the jaws and the inclination of the occlusal plane by dental effects is excluded.

Four angles were measured (see Figure 2 for example of measurement method):

a) Inclination of mandibular first molar to palatal plane

- Line drawn through apex of mesial root through mesiobuccal cusp of crown

b) Inclination of mandibular first premolar

- Line drawn through apex of root through center of cusp

c) Inclination of mandibular canine

- Line drawn through apex of root through center of cusp

d) Inclination of mandibular central incisor

- Line drawn through apex of root through incisal edge

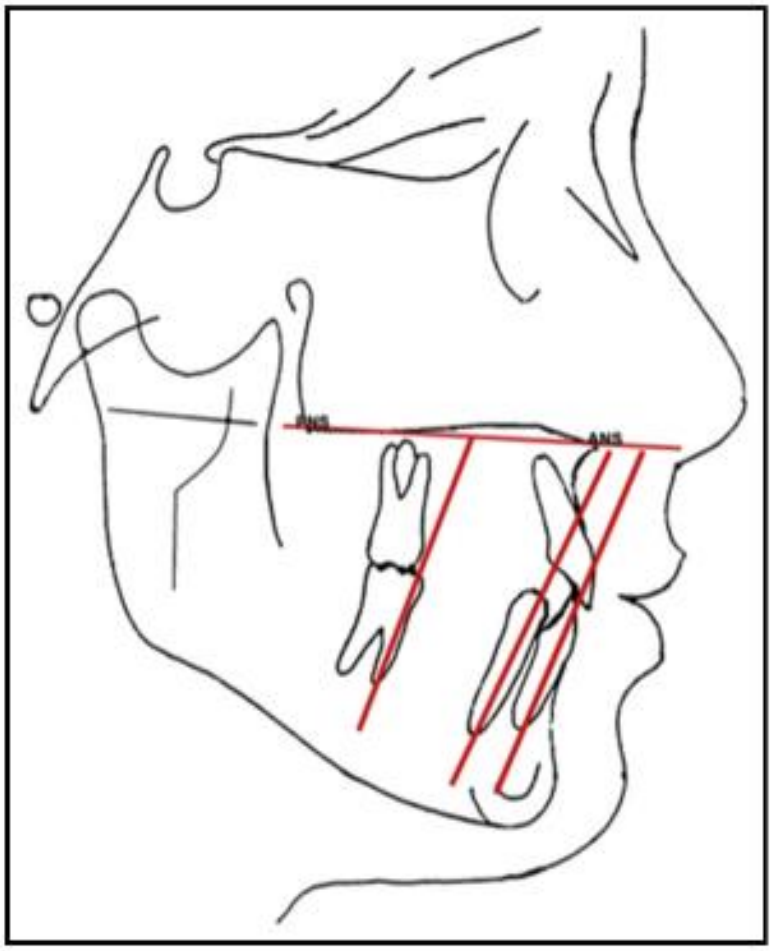

Figure 3: Cephalometric film with reference plane at palatal plane (Yoshihara 2000)

2.2.3 Measuring Occlusal Curves

To measure the occlusal curves a conceptual method of placing spheres on the models and measuring the resulting radii was proposed (Feldman et al 2015). This method of measuring the curve of Spee attempted to adhere to Baydas' method (Baydas et al 2004). This commonly used method averages the right and left perpendicular distances between the deepest cusp tip and a flat plane that was laid on top of the mandibular dental cast, touching the incisal edges of the central incisors and the distal cusp tips of the most posterior teeth in the lower arch (Baydas et al 2004). The most posterior teeth in the arch of our sample at T0 and T1 were the first molars.

From 3D scans of dental casts, points on digitized models were placed to form the curve of Spee, curve of Wilson and Monson's spheres (see Figure 4). The radii of the spheres correspond to the depth of the occlusal curvatures; the steeper the curvature, the smaller the radius. The spherical radii were chosen as outcomes of occlusal curve changes because this method, combined with conventional cephalometric radiographs, can help to identify the different tooth movements contributing to occlusal curve changes in serial extraction patients. Three separate spheres were produced according to the following landmark locations:

a) **Curve of Spee (anteroposterior curve, viewed in the sagittal plane)**

- MB and DB cusps of mandibular first molars
- Incisal edges for four mandibular incisors

b) **Curve of Wilson (mediolateral curve, viewed in the frontal plane)**

- MB, ML, DB and DL cusps of mandibular first molars

c) **Monson's spheres**

- MB, ML, DB and DL cusps of mandibular first molars
- Incisal edges for four mandibular incisors

It should be noted that we chose to not consider the second molars for our outcomes because at the start of treatment, namely T0 and T1, the second molars were unerupted in the control and serial extraction samples.

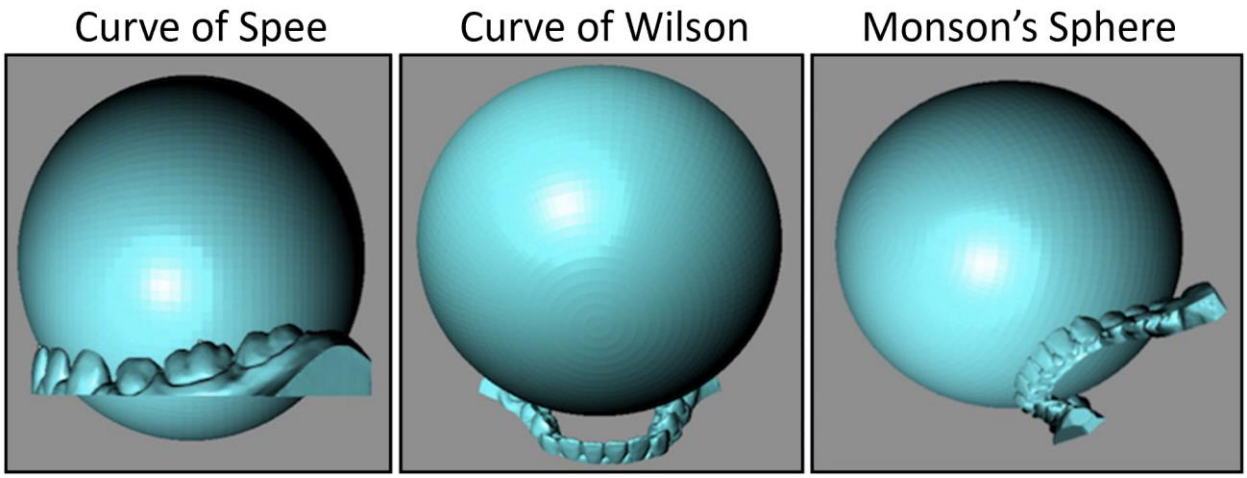

Figure 4: 3D Renderings of the Spheres Representing Occlusal Curves

2.3 Statistical Analysis

A power calculation was done for detecting differences in tooth tipping and the occlusal curves; a 90% power and an α=0.05 would require 22 patients in each group. SPSS version 25.0 was used for all statistical analyses and the threshold for the statistical significance for all tests was set at $P<0.05$. For the collected data, assumptions were made that both normality and equality of variances existed. A table of measurements were compiled for each time point, T0, T1 and T2, including the mean and standard deviation for each group measuring the occlusal curves and each group measuring the dental tipping. Since there were no values that were significant in the tests of homogeneity of variance we went on to use one-way analysis of variance (ANOVA) to see if there was a significant difference between groups. A post hoc test was then used to determine between which two groups that a significant difference existed. In our study we chose to use a Bonferroni post hoc comparison to identify where a significant difference existed between two specific groups. A one-way ANOVA test was carried out to assess for significant differences in ages between all groups at timepoints T0, T1 and T2.

Chapter 3: Results

The intra-examiner agreement was tested based on duplicate recordings of 10 randomly selected samples. The intra-class correlation coefficients for occlusal curves were as follo3ws: for the Curve of Spee 0.865, Monson's sphere 0.931 and for the Curve of Wilson 0.990 (for the combined data of occlusal curves 0.986). For the tipping measurements the correspondent values were as follows: PP-L1 0.962, PP-L3 0.932, PP-L4 0.879 and for PP-L6 0.774 (for the combined data for tipping 0.971). The findings of this testing showed that all measurements were acquired with high degree of intra-examiner reliability.

85 total patients were measured in this study over three time points T0, T1 and T2 (except for Late Ext 5 group which was only measured at T1 and T2). The Control group was age matched at T0 to the Early Ext 5 group, while Late Ext 5 group was age matched at T1 to the Early Ext 5 group. The Early Ext E group only had a sample size of 10 subjects and could not actively be age matched at T0 to the Early Ext 5 group. No significant differences were found between any groups for age at T0, T1, or T2 (Table 2). The age range at T0 was 10.0-10.8 years old, at T1 the range was 12.6-13.1 years old, and at T2 the range was 15.4-15.6 years old.

Table 1: Summary of Ages at T0, T1 and T2

AGE		# of patients	Age at T0	Age at T1	Age at T2
Group 1: Early ext 5's	Mean (std dev)	25	10.7 (1.2)	13.1 (1.1)	15.5 (1.3)
Group 2: Early ext E's	Mean (std dev)	10	10.0 (1.8)	13.0 (1.2)	15.5 (1.1)
Group 3: Late ext 5's	Mean (std dev)	25	-	12.6 (1.3)	15.4 (1.3)
Group 4: Control	Mean (std dev)	25	10.8 (0.9)	12.9 (0.9)	15.6 (1.1)

**Unit of measurement is in years*

Table 2: One-way ANOVA of age between groups at T0, T1 and T2

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Age at T0	Between Groups	5.618	2	2.809	1.932	0.154
Age at T1	Between Groups	2.464	3	0.821	0.649	0.586
Age at T2	Between Groups	0.283	3	0.094	0.066	0.978

3.1 Occlusal Curves

The following table summarizes the results seen from measurement of the occlusal curves from all test groups at each time point.

Table 3: Summary of Occlusal Curve Results

OCCLUSAL CURVES		T0			T1			T2		
		M	**COW**	**COS**	**M**	**COW**	**COS**	**M**	**COW**	**COS**
Group 1: Early ext 5's	Mean (std dev)	54.0 (4.4)	58.2 (5.9)	30.7 (4.6)	51.6 (4.5)	56.6 (5.5)	29.9 (4.9)	55.4 (3.5)	61.1 (4.1)	25.0 (4.3)
Group 2: Early ext E's	Mean (std dev)	52.8 (5.2)	55.2 (6.7)	32.6 (4.6)	48.5 (3.5)	53.8 (4.8)	29.8 (3.3)	55.5 (2.8)	61.1 (3.8)	28.4 (6.6)
Group 3: Late ext 5's	Mean (std dev)	-	-	-	56.8 (5.7)	61.4 (7.6)	31.5 (3.8)	57.5 (4.1)	63.8 (4.7)	26.4 (3.7)
Group 4: Control	Mean (std dev)	53.8 (2.7)	58.5 (3.6)	28.7 (4.7)	54.1 (4.0)	59.1 (5.3)	29.4 (4.4)	54.6 (4.5)	60.1 (5.9)	28.8 (4.1)

**Unit of measurement is in mm (radius of each sphere is measured in mm)*
***Larger values indicate flatter occlusal curves; smaller values indicate steeper occlusal curves*

Table 4 summarizes the changes in the radii of occlusal curves from each test group between T0 and T1 and between T1 and T2.

Table 4: Summary of Changes in Occlusal Curves from T0 to T1 and T1 to T2

OCCLUSAL CURVES	Change from T0 to T1			Change from T1 to T2		
	M	**COW**	**COS**	**M**	**COW**	**COS**
Group 1: Early ext 5's	-2.4	-1.5	-0.8	3.8	4.4	-4.8
Group 2: Early ext E's	-4.3	-1.4	-2.8	7.0	7.3	-1.4
Group 3: Late ext 5's	-	-	-	0.7	2.4	-5.1
Group 4: Control	0.3	0.6	0.7	0.5	1.0	-0.6

**Unit of measurement is in mm (radius of each sphere is measured in mm)*
+ change indicates flattening of occlusal curves
- change indicates steepening of the occlusal curves

Differences in occlusal curves between groups at each time point were assessed using a One-Way ANOVA test with a Post Hoc Bonferroni adjustment for multiple comparisons, the findings of this testing is included in Table 5. Occlusal curve results show that at T0 there were no significant differences in occlusal curves between groups. Since the late extraction group did not have any records taken at T0, there were no measurements for occlusal curves at this time.

From T0 to T1 all three occlusal curves experienced steepening in the two early extraction groups, while the control group had minimal flattening of occlusal curves (see table 4). At T1, there were significant differences in Monson's Sphere and Curve of Wilson between early and late extraction groups as the occlusal curves steepened in the early extraction groups. The significant differences between groups for each occlusal curve at T1 are shown in table 5.

From T1 to T2 both the Monson's sphere and Curve of Wilson experienced flattening of their curves in all four groups, but most significantly in the two early extraction groups (see table 4). However, from T1 to T2, the results show steepening in the Curve of Spee for all four groups (see table 4). At T2 the differences in Monson's sphere and the Curve of Wilson were fully corrected by flattening of the occlusal curves and there were no significant differences between any groups at T2, except for one significant difference in the Curve of Spee between the early extraction of 5's and control groups (see table 5).

Table 5: Multiple Comparisons Bonferroni Test of Differences in Occlusal Curves

Multiple Comparisons Occlusal Curves#											
			T0			T1			T2		
Occlusal Curves	**Test Groups**		**Mean Difference**	**Std. Error**	**Sig.**	**Mean Difference**	**Std. Error**	**Sig.**	**Mean Difference**	**Std. Error**	**Sig.**
Monson Radius	Early extraction 5	Early extraction E	1.2	1.5	1.000	3.1	1.8	0.473	-0.1	1.5	1.000
		Late extraction 5	-	-	-	-5.2*	1.3	0.001	-2.1	1.1	0.353
		Control	0.1	1.1	1.000	-2.5	1.3	0.357	0.8	1.1	1.000
	Early extraction E	Late extraction 5	-	-	-	-8.4*	1.8	0.000	-2.1	1.5	0.996
		Control	-1.0	1.5	1.000	-5.6*	1.8	0.011	0.9	1.5	1.000
	Late extraction 5	Control	-	-	-	2.7	1.3	0.262	2.9	1.1	0.058
COW Radius	Early extraction 5	Early extraction E	2.9	2.0	0.417	2.8	2.3	1.000	0.0	1.8	1.000
		Late extraction 5	-	-	-	-4.8*	1.7	0.041	-2.7	1.4	0.304
		Control	-0.4	1.5	1.000	-2.5	1.7	0.914	1.0	1.4	1.000
	Early extraction E	Late extraction 5	-	-	-	-7.6*	2.3	0.008	-2.7	1.8	0.853
		Control	-3.3	2.0	0.289	-5.3	2.3	0.134	1.0	1.8	1.000
	Late extraction 5	Control	-	-	-	2.3	1.7	1.000	3.7	1.4	0.051
COS Radius	Early extraction 5	Early extraction E	-1.9	1.7	0.808	0.1	1.6	1.000	-3.4	1.6	0.259
		Late extraction 5	-	-	-	-1.7	1.2	1.000	-1.4	1.2	1.000
		Control	1.9	1.3	0.446	0.4	1.2	1.000	-3.8*	1.2	0.018
	Early extraction E	Late extraction 5	-	-	-	-1.8	1.6	1.000	2.0	1.6	1.000
		Control	3.9	1.7	0.091	0.4	1.6	1.000	-0.4	1.6	1.000
	Late extraction 5	Control	-	-	-	2.1	1.2	0.515	-2.4	1.2	0.325

* The mean difference is significant at the 0.05 level.

One-way ANOVA with Post Hoc Bonferroni adjustment

Focusing on only Monson's sphere from T0, T1 and T2 between all groups the box plots in figure 5 show that at T0 there were no substantial differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1 a steepening can be seen in the Monson's sphere for both the Early 5's and Early E's groups as the radii decreased. At T1 there was a substantial difference between the Early 5's group and Late 5's group, as well as between the Early E's group and both the Late 5's and Control groups, with the early extraction groups having steeper Monson's spheres. At T2 there was significant flattening of Monson's sphere for the two early extraction groups and as a result there were no differences in Monson's sphere between all groups.

The following box plot graphs help visualize the differences in the radii of Monson's spheres seen between groups at T0, T1 and T2.

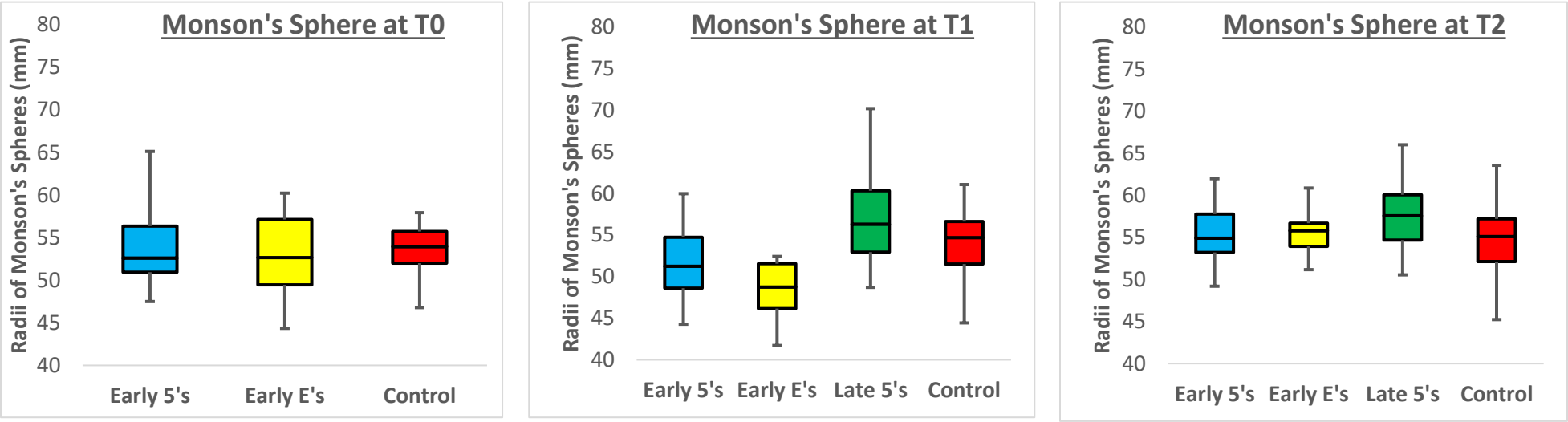

Figure 5: Box plot of Monson's Spheres between all groups at T0, T1 and T2

Focusing on only the Curve of Wilson spheres from T0, T1 and T2 between all groups the following graphs in figure 6 show that at T0 there were no differences among all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1 a steepening can be seen in the Curve of Wilson for both the Early 5's and Early E's groups as the radii decreased. At T1 there was a difference between the Early 5's group and Late 5's group, as well as between the Early E's group and the Late 5's group, the early extraction groups having steeper Curve of Wilson spheres. At T2 there was significant flattening of the Curve of Wilson spheres for the two early extraction groups and as a result there were no differences in the Curve of Wilson spheres between all groups.

The following box plot graphs help visualize the differences in the radii of Curve of Wilson spheres seen between groups at T0, T1 and T2.

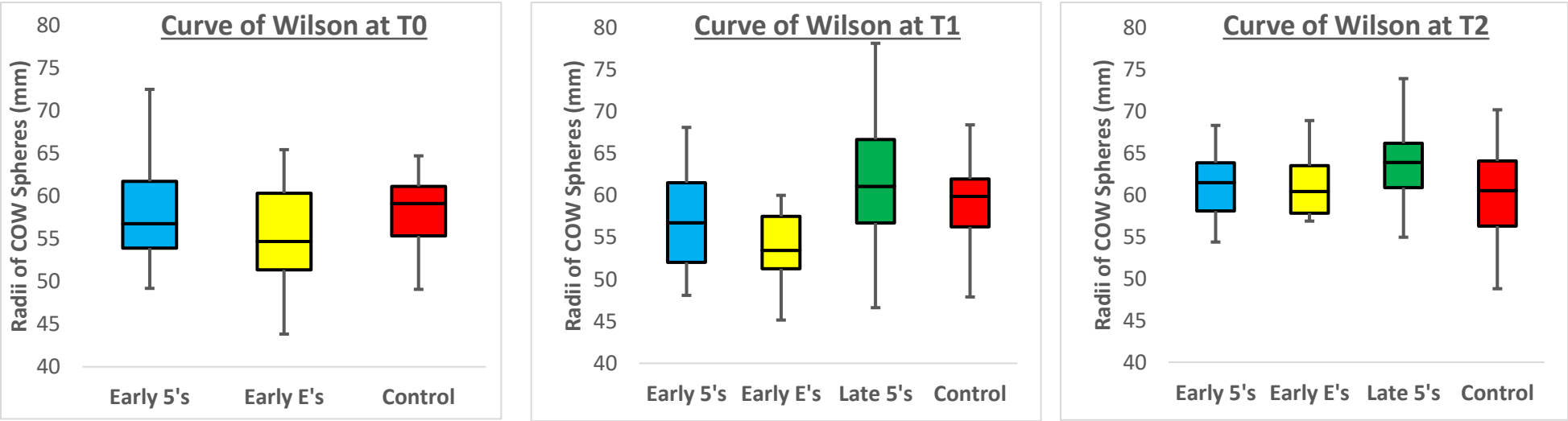

Figure 6: Box plot of Curve of Wilson spheres between all groups at T0, T1 and T2

Focusing on only the Curve of Spee sphere from T0, T1 and T2 between all groups the following graphs in figure 7 show that at T0 there were no differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1 a steepening can be seen in the Curve of Spee for both the Early 5's and Early E's groups as the radii decreased. At T1 there were no significant differences between any groups. At T2 there was further steepening of the Curve of Spee spheres for all groups. There was only one visible difference found at T2 which was between the Early Ext 5's and Control group.

The following box plot graphs help visualize the differences in the radii of Curve of Spee spheres seen between groups at T0, T1 and T2.

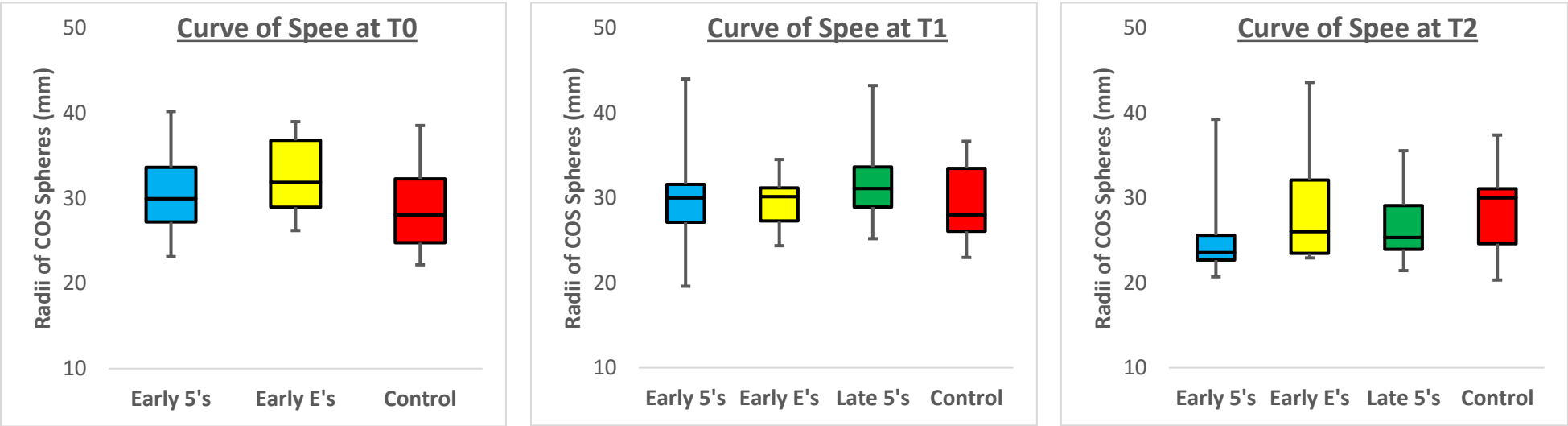

Figure 7: Box plot of Curve of Spee spheres between all groups at T0, T1 and T2

3.2 Dental Tipping

Table 6 summarizes the results seen from measurement of tooth tipping for all test groups at each time point.

Table 6: Summary of Tooth Tipping Results

ANGULATION OF TEETH		T0				T1				T2			
		L6-PP	**L4-PP**	**L3-PP**	**L1-PP**	**L6-PP**	**L4-PP**	**L3-PP**	**L1-PP**	**L6-PP**	**L4-PP**	**L3-PP**	**L1-PP**
Group 1: Early ext 5's	Mean (std dev)	68.1 (4.1)	72.9 (7.2)	67.9 (6.5)	60.6 (7.7)	62.1 (4.3)	86.4 (5.8)	75.1 (6.6)	61.8 (5.4)	72.2 (5.0)	72.5 (4.3)	66.9 (5.6)	58.7 (6.6)
Group 2: Early ext E's	Mean (std dev)	70.4 (7.9)	73.5 (9.6)	71.1 (8.2)	62.1 (10.2)	64.1 (6.1)	85.2 (5.6)	76.2 (7.8)	64.6 (10.3)	73.6 (5.0)	73.8 (4.6)	69.6 (4.8)	64.2 (9.2)
Group 3: Late ext 5's	Mean (std dev)	-	-	-	-	69.1 (6.7)	73.7 (6.7)	64.8 (4.7)	58.2 (5.8)	71.4 (4.8)	71.3 (5.2)	67.1 (5.1)	60.8 (5.2)
Group 4: Control	Mean (std dev)	68.8 (4.7)	75.4 (6.2)	67.0 (6.2)	58.7 (7.5)	70.2 (5.0)	76.5 (4.2)	69.6 (5.7)	60.9 (8.2)	70.9 (5.0)	75.9 (4.4)	69.6 (5.0)	62.3 (8.5)

**Unit of measurement is in degrees (the long axis of each tooth is measured relative to the palatal plane in degrees)*

Table 7 summarizes the changes in tooth angulation from each test group between T0 and T1 and between T1 and T2.

Table 7: Summary of Changes in Tooth Angulation

ANGULATION OF TEETH	Change from T0 to T1				Change from T1 to T2			
	L6-PP	**L4-PP**	**L3-PP**	**L1-PP**	**L6-PP**	**L4-PP**	**L3-PP**	**L1-PP**
Group 1: Early ext 5's	-6.0	13.5	7.3	1.2	10.1	-13.8	-8.3	-3.0
Group 2: Early ext E's	-6.3	11.7	5.1	2.5	9.6	-11.4	-6.6	-0.4
Group 3: Late ext 5's	-	-	-	-	2.3	-2.5	2.3	2.6
Group 4: Control	1.5	1.1	2.6	2.2	0.7	-0.5	-0.1	1.3

**Unit of measurement is in degrees*
+ change indicates distal tipping of teeth
- change indicates mesial tipping of teeth

Differences in the angulation of different teeth among groups at each time point were assessed using a Bonferroni multiple comparisons test, included in the following table 8. Tooth tipping results show that at T0 there are no significant differences in tooth angulation between groups. Since the late extraction group did not have any records taken at T0, there were no measurements for tooth angulation at this time.

From T0 to T1 the lower 6's tipped mesially while the lower 4's, 3's and 1's tipped lingually in the two early extraction groups, while the control group had minimal changes in tooth angulation (see table 7). At T1, there were significant differences in the angulation of lower 6's, 4's and 3's between groups as highlighted in table 7. However, the only tooth angulation to show no significant differences at T1 between any groups was the angulation of the lower central incisors.

From T1 to T2 the lower 6's tipped distally while the lower 4's, 3's and 1's tipped mesially in both early extraction groups. The lower incisors tipped lingually a minimal amount in the late extraction and control groups. At T2 the differences in tipping of all teeth were fully corrected in the early extraction groups by uprighting and there were no significant differences between any groups at T2, except for one significant difference in the angulation of lower 4's between the late extraction of 5's and control groups (see table 8).

Table 8: Multiple Comparisons Bonferroni Test of Differences in the Tipping of Teeth

Multiple Comparisons Tooth Angulation#											
			T0			T1			T2		
Tooth Angulation	Test Groups		Mean Difference	Std. Error	Sig.	Mean Difference	Std. Error	Sig.	Mean Difference	Std. Error	Sig.
PP to L6	Early extraction 5	Early extraction E	-2.2	1.9	0.761	-1.9	2.1	1.000	-1.4	1.8	1.000
		Late extraction 5	-	-	-	-7.0*	1.6	0.000	0.8	1.4	1.000
		Control	-0.6	1.4	1.000	-8.1*	1.6	0.000	1.3	1.4	1.000
	Early extraction E	Late extraction 5	-	-	-	-5.0	2.1	0.099	2.2	1.8	1.000
		Control	1.6	1.9	1.000	-6.2*	2.1	0.022	2.7	1.8	0.893
	Late extraction 5	Control	-	-	-	-1.1	1.6	1.000	0.4	1.4	1.000
PP to L4	Early extraction 5	Early extraction E	-0.5	2.7	1.000	1.2	2.1	1.000	-1.3	1.7	1.000
		Late extraction 5	-	-	-	12.7*	1.6	0.000	1.3	1.3	1.000
		Control	-2.5	2.0	0.677	9.9*	1.6	0.000	-3.4	1.3	0.073
	Early extraction E	Late extraction 5	-	-	-	11.5*	2.1	0.000	2.5	1.7	0.896
		Control	-2.0	2.7	1.000	8.7*	2.1	0.001	-2.1	1.7	1.000
	Late extraction 5	Control	-	-	-	-2.8	1.6	0.538	-4.7*	1.3	0.004
PP to L3	Early extraction 5	Early extraction E	-3.2	2.5	0.600	-1.0	2.2	1.000	-2.7	1.9	0.990
		Late extraction 5	-	-	-	10.3*	1.7	0.000	-0.3	1.5	1.000
		Control	0.8	1.9	1.000	5.5*	1.7	0.010	-2.7	1.5	0.413
	Early extraction E	Late extraction 5	-	-	-	11.3*	2.2	0.000	2.4	1.9	1.000
		Control	4.1	2.5	0.326	6.5*	2.2	0.026	0.0	1.9	1.000
	Late extraction 5	Control	-	-	-	-4.8*	1.7	0.034	-2.4	1.5	0.610
PP to L1	Early extraction 5	Early extraction E	-1.5	3.0	1.000	-2.8	2.7	1.000	-5.5	2.7	0.273
		Late extraction 5	-	-	-	3.6	2.0	0.472	-2.0	2.0	1.000
		Control	1.9	2.3	1.000	0.9	2.0	1.000	-3.5	2.0	0.531
	Early extraction E	Late extraction 5	-	-	-	6.4	2.7	0.112	3.4	2.7	1.000
		Control	3.4	3.0	0.783	3.7	2.7	1.000	2.0	2.7	1.000
	Late extraction 5	Control	-	-	-	-2.7	2.0	1.000	-1.5	2.0	1.000

*The mean difference is significant at the 0.05 level.

One-way ANOVA with Post Hoc Bonferroni adjustment

Focusing on only the angulation of lower 6's from T0, T1 and T2 between all groups the following graphs in figure 8 show that at T0 there were no substantial differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1, mesial tipping of the lower 6's can be seen for both the Early 5's and Early E's groups as the angulation decreased. At T1 there were several visible differences between groups as identified in table 8. At T2 there was distal tipping of the lower 6's in both early extraction groups and as a result there were no differences between groups at T2.

The following box plot graphs help visualize the differences in the tipping of lower first molars seen between groups at T0, T1 and T2.

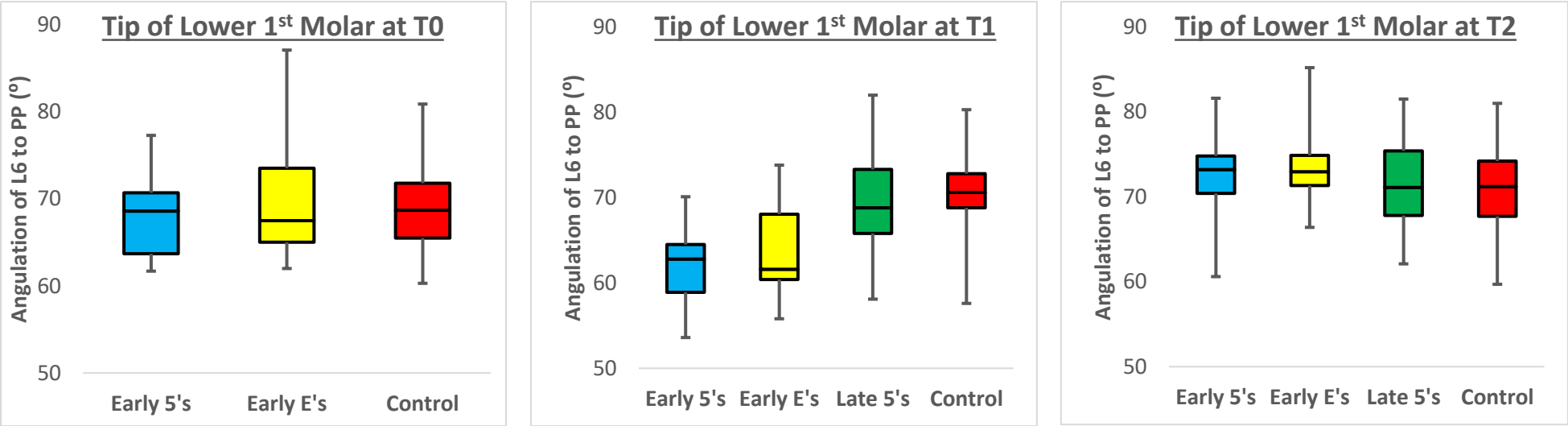

Figure 8: Box plot of lower first molar tipping between all groups at T0, T1 and T2

Focusing on only the angulation of lower 4's from T0, T1 and T2 between all groups the following graphs in figure 9 show that at T0 there were no substantial differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1, distal tipping of the lower 4's can be seen for both the Early 5's and Early E's groups as the angulation increased with minimal distal tipping of the control group. At T1 there were several visible differences between groups as identified in table 8. At T2 there was mesial tipping of the lower 4's in all groups and as a result there were no differences between groups at T2, except for one visible difference between late extraction of 5's and control groups.

The following box plot graphs help visualize the differences in the tipping of lower first premolars seen between groups at T0, T1 and T2.

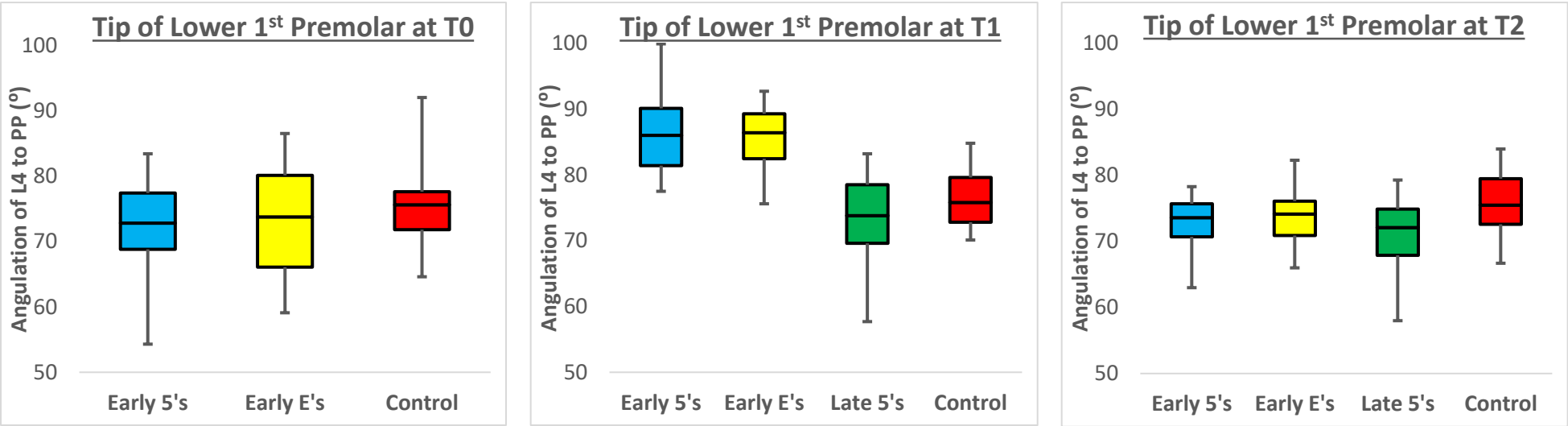

Figure 9: Box plot of lower first premolar tipping between all groups at T0, T1 and T2

Focusing on only the angulation of lower 3's from T0, T1 and T2 between all groups the following graphs in figure 10 show that at T0 there were no substantial differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1, distal tipping of the lower 3's can be seen for both the Early 5's and Early E's groups as the angulation increased with minimal distal tipping of the control group. At T1 there were visible differences between all groups except that of the two early extraction groups (see table 8). At T2 there was mesial tipping of the lower 3's in both early extraction groups and as a result there were no differences between any groups at T2.

The following box plot graphs help visualize the differences in the tipping of lower canines seen between groups at T0, T1 and T2.

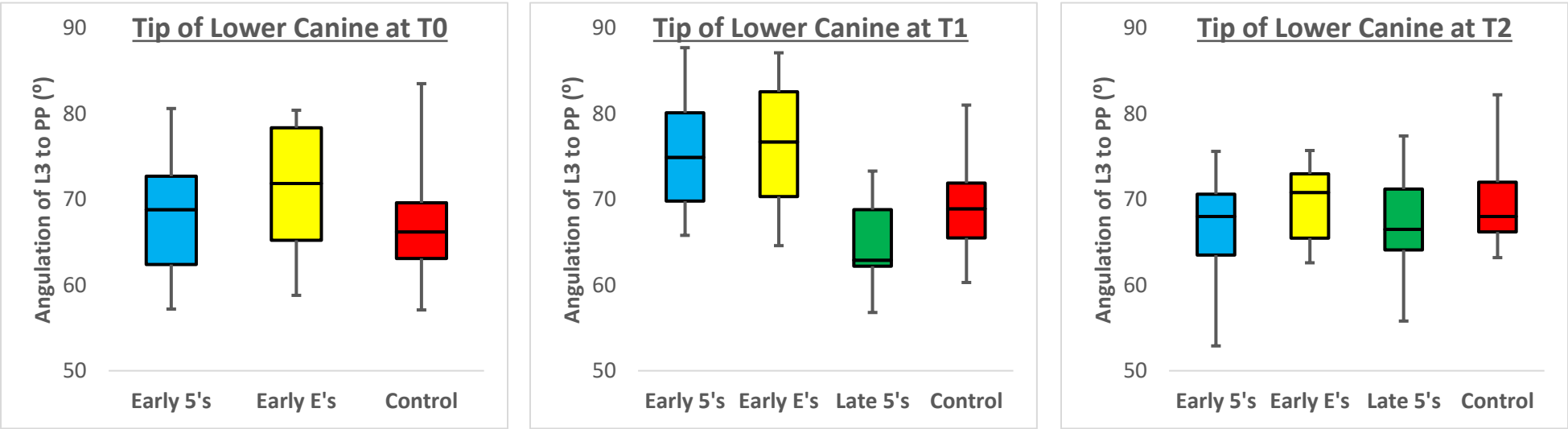

Figure 10: Box plot of lower canine tipping between all groups at T0, T1 and T2

Focusing on only the angulation of lower 1's from T0, T1 and T2 between all groups the following graphs in figure 11 show that at T0 there were no substantial differences between all groups of Early 5's, Early E's and Control (the Late 5's group did not have data collected for T0). At T1, minimal distal tipping of the lower 1's can be seen for the Early 5's, Early E's and control groups as the angulation only minimally increased. At T1 there were no visible differences between any groups (see table 8). At T2 there was minimal mesial tipping of the lower 1's in both early extraction groups, back near pre-treatment angulations, while the late extraction group had minimal lingual tipping of the lower 1's. As a result there were no differences between any groups at T2.

The following box plot graphs help visualize the differences in the tipping of lower central incisors seen between groups at T0, T1 and T2.

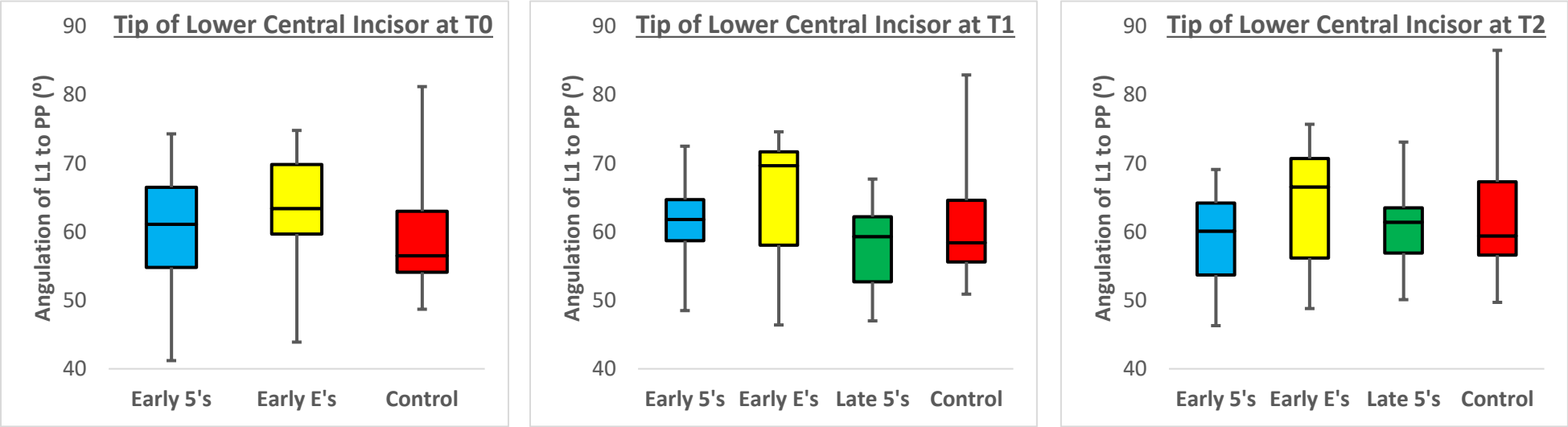

Figure 11: Box plot of lower central incisor tipping between all groups at T0, T1 and T2

Chapter 4: Discussion

4.1 General Discussion

This study evaluated the effects that serial extraction of mandibular second premolars, or deciduous mandibular second molars when the second premolars were missing, had on both occlusal curves and tipping of adjacent teeth. We compared this data to a group of second premolar late extractions, and an untreated control. To our knowledge, a study on dental tipping following serial extraction of this specific subset focusing on second premolars and deciduous second molars has only been previously investigated by Lindqvist and Mamopoulou (Lindqvist 1980; Mamopoulou et al 1996). However, no past studies have evaluated occlusal curve changes in a group of patients with serial extraction of mandibular second premolars or deciduous mandibular second molars when the second premolars were missing.

There was a significant steepening of occlusal curves of both Monson's sphere and the Curve of Wilson from before serial extraction (T0) to after extraction and physiologic drift, but prior to fixed orthodontic treatment (T1). The steepening of these two curves were fully corrected by fixed orthodontic treatment. The Curve of Spee showed some mild steepening from T0 to T1 in both early extraction groups, but no significant differences existed between any group at T1, which requires further discussion. We would have expected steepening in an amount similar to the Curve of Wilson and Monson's spheres. Our data showed further steepening of the Curve of Spee from T1 to T2 in all groups. This specific finding is not what orthodontists see clinically, as the Curve of Spee is flattened by comprehensive fixed orthodontic treatment. Further discussion of this finding is explained later in the limitations of the study.

The measurements of lateral cephalometric films documented tooth tipping following serial extraction that the occlusal curves did not describe. Both early extraction groups showed

significant tipping of mandibular first molars, first premolars and canines from before extraction to after extraction and physiologic drift; the molars tipped mesially and first premolars and canines tipped distally. While there was some mild lingual tipping of the mandibular central incisors in both early extraction groups from T0 to T1, there were no significant lower incisor angulation differences between any groups at T1. Orthodontists avoid serial extractions because of potential lingual tipping of lower incisors and resulting facial profile flattening. Our study showed that following mandibular second premolar, or deciduous second molar, serial extraction and drift, there was no significant difference in lower incisor position before starting fixed orthodontic treatment. The significant tipping of the lower first molars, first premolars and canines were fully corrected by fixed orthodontic treatment. At T2, there were no significant differences in lower incisor angulation between any groups. When lower second premolars, or deciduous lower second molars, are extracted early there will be no significant difference in final lower incisor angulation compared to delaying extraction to the full permanent dentition.

It is critical to highlight how these findings impact an orthodontist's clinical practice. The goal was to contribute information about the above mentioned serial extraction patterns to encourage clinicians to perform evidence-based orthodontics; namely when and why to use serial extraction of second premolars or deciduous second molars. There has been a constant debate among orthodontists about whether a tooth size arch length discrepancy should be treated with a non-extraction or an extraction approach (Vaden, Dale, & Klontz, 2011). If an orthodontist decides on extractions, then they must decide on the optimal timing to obtain minimal side effects and maximum benefits. Our study quantified the negative changes following serial extraction, and if any significant differences existed compared to late extraction, following comprehensive orthodontic treatment. Negative side effects from one treatment protocol should

be evaluated at all time points. If the end result shows no difference between two different treatment methods, then one should ask if there is warranted concern over transient tipping and steepening of occlusal curves, especially if the serial extraction protocol provided many other benefits, such as spontaneous space closure, improvement in alignment and other noted advantages in the literature.

Part of this study rationale was to quantify and compare the results from serial extraction of lower second premolars and deciduous second molars to first premolar serial extraction. The vast majority of serial extractions performed involve first premolar removal and the effects seen from these have been well documented (Feldman et al 2015). We mirrored many of Feldman's measurement methods so that a direct comparison could be made (Feldman et al 2015).

Feldman found the average lower incisor lingual tipping was 4.3 degrees, following extraction and physiologic drift (Feldman et al 2015). Our early second premolar and deciduous second molar extraction groups showed less lingual tipping. From T0 to T1, the early extraction of 5's group saw an average of 1.2 degrees of lingual tipping and the early extraction of E's group saw 2.5 degrees of lingual tipping. This reduced lingual tipping of lower incisors from T0 to T1 is due to extractions being done further posteriorly. Feldman saw an average of 0.07 degrees of labial tipping of lower incisors from T1 to T2 in her serial extraction group, while we saw labial tipping of 3.0 degrees and 0.4 degrees of lower incisors in the early extraction of 5's and early extraction of E's groups, respectively (Feldman et al 2015). Lower canines tipped distally an average of 6.70 degrees after first premolar extraction, while we found an average of 7.3 degrees and 5.1 degrees of distal tipping in the early extraction of 5's and early extraction of E's groups, respectively (Feldman et al 2015). We would have expected more distal tipping of canines when the first premolars were extracted from T0 to T1. These results show

approximately the same amount of distal tipping in lower canines when the 4's or the 5's (or E's) were extracted (Feldman et al 2015). Feldman reported lower canine uprighting of 4.38 degrees during fixed orthodontic treatment, while we saw lower canine uprighting of 8.3 degrees and 6.6 degrees in the early extraction of 5's and early extraction of E's groups, respectively (Feldman et al 2015). Feldman's lower first molars tipped mesially 1.53 degrees from T0 to T1, while our study found lower first molar mesial tipping of 6.0 degrees and 6.3 degrees in the early extraction of 5's and early extraction of E's groups, respectively (Feldman et al 2015). This was expected clinically, as extracting the 5's or E's immediately anterior to the first molar caused more significant mesial tipping in our study compared to minimal tipping of the first molar when the 4's were extracted by Feldman's study (Feldman et al 2015). During braces, Feldman's lower tipped molars uprighted 3.07 degrees, while in our study the first molar uprighted 10.1 degrees and 9.6 degrees in the early extraction of 5's and early extraction of E's groups, respectively (Feldman et al 2015). Therefore, the more mesial tipping of the first molars after extraction and drift, the more distal tipping or uprighting was required during fixed orthodontic treatment.

During orthodontic treatment, Feldman's late first premolar extraction group saw lingual tipping of 6.2 degrees for the incisors, distal tipping of 2.2 degrees for the canines and distal tipping of 2.2 degrees for the first molars (Feldman et al 2015). This was compared to our late extraction of 5's group that saw, during braces, lingual tipping of 2.6 degrees for the incisors, distal tipping of 2.3 degrees for the canines and distal tipping of 2.3 degrees for the first molars. When extracting lower 5's instead of lower 4's, there will be less lingual tipping of incisors and approximately the same amount of minimal distal tipping of canines and molars. This data supports that extracting lower 5's will have a less negative effect on the lower incisor position.

We compared the differences in occlusal curves when either the 4's or 5's (or E's) were extracted early (Feldman et al 2015). Feldman's first premolar serial extraction group found a statistically significant decrease in the radii for all three groups of Monson's sphere, Curve of Wilson and Curve of Spee from T0 to T1 (Feldman et al 2015). Our study found a similar statistically significant decrease in the radii for the two groups of Monson's sphere and Curve of Wilson for both early extraction groups, with a non-statistically significant decrease in the Curve of Spee from T0 to T1. In both early extraction of 4's and of 5's (or E's), there was steepening of all three occlusal curves from T0 to T1, following extraction and physiologic drift. During braces, Feldman's serial extraction group had a statistically significant increase in radii for both Monson's sphere and Curve of Wilson, and a non-statistically significant decrease in the Curve of Spee (Feldman et al 2015). In our study both early extraction groups had significant increases in radii for Monson's sphere and the Curve of Wilson, from braces, while both groups had decreases in the Curve of Spee (a statistically significant decrease in the early extraction of 5's group and a non-statistically significant decrease in the early extraction of E's group). In both Feldman's study and our own, there was flattening of Monson's sphere and the Curve of Wilson following fixed orthodontic treatment. However, we both found decreases in the Curve of Spee from T1 to T2. This does not coincide with clinical observation of a flattened curve of Spee seen following orthodontic treatment. Possible explanations are included further on in this discussion.

We compared occlusal curve changes between Feldman's late lower first premolar extractions to our late lower second premolar extractions (Feldman et al 2015). In Feldman's study, she found from T1 to T2 that there was a non-statistically significant increase in Monson's sphere, a statistically significant increase in the Curve of Wilson and a statistically significant decrease in the Curve of Spee (Feldman et al 2015). In our study, from T1 to T2, we found non-

statistically significant increases in Monson's sphere and the Curve of Wilson and a statistically significant decrease in the Curve of Spee. Both studies parallel each other in that the Monson's sphere and Curve of Wilson flattened as a result of orthodontic treatment. While there was a decrease in the radii of the Curve of Spee in both groups from before to after fixed orthodontic treatment, this was not seen clinically.

To summarize the important findings comparing serial extraction of lower 4's versus lower 5's (or E's), there was less lingual tipping of lower incisors, similar tipping of canines and more mesial tipping of first molars following physiologic drift when 5's or E's were extracted. In terms of occlusal curves, the serial extraction groups of lower 4's from Feldman and lower 5's and E's from our study showed steepening of Monson's sphere, Curve of Wilson and the Curve of Spee following extraction and drift, with flattening of both Monson's sphere and the Curve of Wilson from before to after fixed orthodontic treatment. Comparing the late premolar extraction of lower 4's versus 5's, there was less lingual tipping of lower incisors and similar tipping of canines and molars when lower 5's were extracted in the full permanent dentition compared to lower 4's. For both late premolar extraction of 4's and 5's, there was flattening of Monson's sphere and the Curve of Wilson, but steepening of the Curve of Spee, as a result of fixed orthodontic treatment.

4.2 Limitations of the Study

There are several limitations of this study with the major one concerning the Curve of Spee measurement. A decrease in the radii of the Curve of Spee was seen in all four groups during fixed orthodontic treatment (T1 to T2) which was not observed on the models. This requires an answer to two questions: 1) Did our method accurately measure the Curve of Spee?

2) If we are confident our methodology accurately measured the Curve of Spee, then why did we see steepening of the Curve of Spee, from T1 to T2, when we clinically see a flattening of the Curve of Spee? Our study tried to represent the typical Curve of Spee from a linear measurement to that of a representational sphere. In our study, we placed 8 points in creating the Curve of Spee, plotting points on casts on the DB and MB of both first molars as well as the incisal edges of the four lower incisors. This is compared to the conventional 3 point tripod method of placing a point on the most DB cusp of each first molar and one single incisal point, used in placing a flat plane to measure the linear measurement of the Curve of Spee. There is some inherent risk of not accurately representing a typical linear measurement when trying to display in 3D spheres, along with the further possibility of inaccuracy of placement of 8 points representing the 3D sphere compared to the typical 3 point tripoding. This spherical method representing the Curve of Spee was utilized by Feldman with similar limitations discussed (Feldman et al 2015). In any future project analyzing the Curve of Spee, digitized points could be placed on the models, on the DB cusps of the first molars and a single incisal point. One could then easily take a linear measurement from this digital flat plane to the occlusal surface of the tooth furthest from this plane on each side. The Curve of Spee can be evaluated individually per side, as well by averaging the right and left linear measurements. This proposed methodology would better represent the measurements made clinically by orthodontists and would likely be a much more accurate and reliable methodology for measuring the Curve of Spee.

Another consideration for the possible decrease in the Curve of Spee in all groups from T1 to T2, could be due to the shortening of the dental arch following extraction and space closure. Due to the nature of measuring the radius of each sphere, it is important to note that a lower dental arch that may have the Curve of Spee measurement done linearly from a flat plane

to lowest tooth could have significantly different Curve of Spee measurements if one arch is considerably shorter anterioposteriorly, as with lower premolar extractions. In a shortened dental arch, if all other points were the same, the radius of the sphere would decrease. This radius decrease would show as a steepened Curve of Spee, as in both Feldman's and our study (Feldman et al 2015). We reported a decrease in the Curve of Spee due to this shortened arch length and decreased radius, even when there is actual flattening of the Curve of Spee in terms of linear measurement.

The sphere method for measuring the Curve of Spee is equally vulnerable to changes in buccolingual molar angulation and arch width. The sphere representing the Curve of Spee will either rise or sink vertically to match the specified points. In doing this, any attempt to fit the sphere to the buccal cusps only, while omitting the lingual cusps, is affected by the entire shape of the arch. This negative side effect is mitigated if lingual cusps of the lower first molars are included in the sphere representing the Curve of Spee. This is due the inability for the sphere to sink down as much when the lingual molar cusps are accounted for. For example, Monson's sphere is vulnerable to this sphere sinking effect but to a lesser degree than the Curve of Spee since Monson's sphere takes into account the lingual molar cusps.

Another potential study limitation is the effect of lower crowding on changes in tooth angulation or occlusal curves. We did not measure lower crowding present at T0 (or T1 for late extraction of 5's group); one can question whether there is a difference in tipping, or occlusal curve change, with more crowding. And if so, how much of a difference would crowding make? In a serial extraction case with minimal crowding, there would be considerably more tipping and steepening of occlusal curves than a severely crowded case with 14mm of posterior crowding with blocked out lower 5's so that the lower 4's are already in contact with the lower 6's. Since

crowding was not measured, it precludes us from knowing whether all groups were indeed identical in terms of crowding. We speculate that our lower E extraction group had less overall crowding because a serial extraction decision was made for these patients based less on crowding and more on closing the congenitally missing lower second premolar space. Often the decision to manage the missing teeth by extraction of deciduous molars and space closure will supersede other treatment objectives. For example, we may extract a mildly crowded lower arch when the lower 5's are missing and the E's are retained to close space, whereas if that same patient had lower 5's present the case may treated non-extraction. Orthodontists may be more willing to accept the side effects from serial extraction, namely more tipping and steepening of occlusal curves, to avoid prosthetic replacement of two missing lower premolars.

One other study limitation is potential landmark identification error in both the 2D lateral cephalometric radiographs and 3D digital cases. For the 2-dimensional lateral cephalometric radiographs, the quality ranges widely as some films were more than 30 years old with reduced quality. This is compounded with the inherent difficulty in accurate landmark placement on cephalometric films due to the overlapping of bilateral structures. Literature reports that intra-examiner reliability for all coordinates for most landmarks on digital lateral cephalograms have an intraclass correlation coefficient greater than 0.9; the means of landmark identification differed by approximately 1mm in most coordinates (Lagravere et al 2010). We mitigated the amount of landmark error from cephalometric radiographs by selecting landmarks that were more clearly identifiable relative to other options. Palatal plane is based on a plane from anterior nasal spine (ANS) to posterior nasal spine (PNS), with both landmarks highly reproducible due to their definition and opacity (Yoshihara et al 2000). The dental landmarks located were the apices of the lower 6's, 4's, 3's and 1's, along with their corresponding incisal edge or cusp tip.

Due to the overlapping of teeth, some points were more difficult to locate than others. Furthermore, poor contrast along with the loss of overall radiographic quality from the digitization process introduced some landmark identification errors. We did not perform any intra-operator reliability tests, since reported intra-operator reliability of measurements were good with intraclass correlation coefficients of 0.82 (Damstra et al 2010). Even with published recordings of high intra-operator reliability, this is one aspect that if repeated would be recommended, to quantify landmark error. Another source of landmark identification error was from the point placement on the 3-dimensional digital casts. While the casts were digitized in high quality, the landmark placement for cusp tips especially can deviate as some molars present with wear. Thus, for any given patient there may be a range for the most occlusal point on a cusp, which could reduce accuracy and reliability.

The choice of age matching each sample group chronologically may have some inherent limitations compared to skeletal age or dental age matching. While there is reported variation between chronological age, dental age and skeletal age, literature has shown that there is a strong correlation of chronological age with dental age measured with the modified Demirjian method (Safaee et al 2017). Safaee reported no significant differences between chronological age and dental age with a Pearson correlation coefficient of 0.81, with the mean difference in dental age in both male and female calculated to be 0.33 years less than their chronological age (Safaee et al 2017). Because our sample size of 25 subjects per group was relatively small, it is possible that we had a wide range of dental maturity; so it would have been prudent to match the dental age of each group to ensure there were no significant differences at baseline.

4.3 Future Directions

Several possibilities for future direction have already been mentioned in the above limitations to this study. If this study were conducted again, consideration should be given to using a different measurement method for the Curve of Spee, measuring crowding, intra-operator reliability testing for landmark identification error on 2D cephalograms and 3D casts, as well as completing dental age matching for all groups at baseline. Changing the measurement method for the Curve of Spee to one that mimics what is used clinically, such as a linear measurement, would likely serve as both a more accurate method and one that is easier to interpret for orthodontists reading the results of the study. This would be possible using digitized 3D casts in creating a flat plane from plotting of 3 dental points, the DB cusps of first molars and a central incisal point, and measuring the linear distance from the flat plane to the occlusal surface of most gingival tooth, with averaging of left and right sides. It would be valuable to compare the results of the Curve of Spee from this linear measurement method to the sphere method used in our study. The measurement of crowding would also be a significant improvement in this study because it could evaluate if crowding has an effect on tooth tipping and occlusal curve changes, and if so by how much. Intra-operator reliability measuring landmarks on cephalometric radiographs should be tested statistically. Dental age matching would give assurance that all test groups were equal at baseline.

Clinically relevant future research should be focused on orthodontic treatment efficiency with serial extraction of lower 5's or E's. A future study analyzing variables such as the number of appointments, length of time, estimated total chair time, and pre and post treatment PAR scores would help provide evidence of treatment efficiency. The side effects of serial extraction of lower 5's and E's are not as severe as some may have thought, especially lower incisor tipping

after extraction and drift. Since the side effects are fully corrected by orthodontic treatment, treatment efficiency will help determine whether an orthodontist chooses to use second premolar serial extraction. O'Shaughnessy studied treatment efficiency of first premolar serial extraction which could serve as a template for a study evaluating clinical efficiency on serial extraction of lower 5's or E's (O'Shaughnessy et al 2011). O'Shaughnessy compared treatment times and outcomes for serial extraction and late first premolar extraction cases; there was no post treatment difference in PAR scores between the groups, both early and late extraction groups achieved clinically similar outcomes, and the serial extraction group had a significantly reduced average active treatment time of four to six months (O'Shaughnessy et al 2011).

In summary, future studies should focus on better methodology, specifically for measuring the Curve of Spee, emphasis placed on the treatment efficiency of serial extraction of lower 5's and E's, as well as the measurement of crowding to better assess the impact it may have on the amount of dental tipping or change in occlusal curves.

Chapter 5: Conclusions

1. Serial extraction of lower second premolars, or deciduous lower second molars when the second premolars were missing, produced steeper occlusal curves and significant tipping of mandibular first molars, first premolars and canines after extraction and physiologic drift (T1).
2. The tipping of teeth and accentuated occlusal curves of Monson's sphere and the Curve of Wilson were fully corrected following comprehensive fixed orthodontic treatment (T2).
3. Serial extractions involving lower second premolars or deciduous lower second molars did not cause any significant lingual tipping of lower incisors following physiologic drift.

References

Alexander, R. G. (2001). The Principles of the Alexander Discipline. *Seminars in Orthodontics*, *7*(2): 62–66.

Andrews, L. F. (1972). The Six Keys to Normal Occlusion. *American Journal of Orthodontics and Dentofacial Orthopedics*, *62*(3): 296–309.

Baydas, B., Yavuz, I., Atasarai, N., Ceylan, I., & Metin Dagsuyu, I. (2004). Investigation of the Changes in the Positions of Upper and Lower Incisors, Overjet, Overbite, and Irregularity Index in Subjects with Different Depths of Curve of Spee. *The Angle Orthodontist*, *74*(3): 349–355.

Boley, J. C. (2002). Serial extraction revisited: 30 years in retrospect. *American Journal of Orthodontics and Dentofacial Orthopedics*, *121*(6): 575–577.

Brandt, S., and Tweed, C. H. (1967). JPO Interviews Dr. Charles H. Tweed, Part 1. *Journal of Clinical Orthodontics*, *1*(12): 142–148.

Broadbent, B. H. (1937). Bolton Standards and Technique in Orthodontic Practice. *The Angle Orthodontist*, *7*(4): 209–233.

Brodie, A. G. (1953). Late growth changes in the human face. *The Angle Orthodontist*, *23*(3): 146–157.

Casko, J. S., Vaden, J. L., Kokich, V. G., Damone, J., James, R. D., Cangialosi, T. J. (1998). Objective grading system for dental casts and panoramic radiographs. *American Journal of Orthodontics and Dentofacial Orthopedics*, *114*(5): 590-599.

Czochrowska, E.M., Stenvik, A., Bjercke, B., Zachrisson, B.U. (2002). Outcome of tooth transplantation: Survival and success rates 17-41 years posttreatment. *American Journal of Orthodontics and Dentofacial Orthopedics 121*(2): 110–119.

Creekmore, T. D. T. (1982). Teeth want to be straight. *Journal of Clinical Orthodontics*, *16*(11): 745–764.

Damstra, J., Huddleston Slater, J.J.R., Fourie, Z., Ren, Y. (2010). Reliability and the smallest detectable difference of lateral cephalometric measurements. *American Journal of Orthodontics and Dentofacial Orthopedics*, *138*(5): 546.e1-546.e8.

Dugoni, S. and Aubert, M. (2008). Orthodontic treatment in the early mixed dentition: Is this the optimum time to start care? *Oral Health, 98*(8): 64-68,70,72,74.

Feldman, E., Kennedy, D.B., Aleksejuniene, J., Hannam, A.G., Yen, E. H. (2015). Mandibular changes secondary to serial extractions compared with late premolar extractions and controls. *American Journal of Orthodontics and Dentofacial Orthopedics,148*(4): 633-640.

Gianelly, A.A. (1994). Crowding: timing of treatment. The *Angle Orthodontist*, *64*(6): 415-418.

Graber, L.W., Vanarsdall, R.L., Vig, K.W.L. (2012). *Orthodontics: Current Principles and Techniques.* 5th ed., Elsevier. Chapter 13: Interceptive Guidance of Occlusion with Emphasis on Diagnosis, 423-473 (Jack G. Dale, Hali C. Dale).

Graber, T. M. (1971). Serial extraction: A continuous diagnostic and decisional process. *American Journal of Orthodontics and Dentofacial Orthopedics*, *60*(6): 541–575.

"Grading System for Dental Casts and Panoramic Radiographs." *The American Board of Orthodontics*, June 2012, https://www.americanboardortho.com/media/1191/grading-system-casts-radiographs.pdf. Accessed 20 November 2017.

Haruki, T., Little, R.M. (1998). Early versus late treatment of crowded first premolar extraction cases: postretention evaluation of stability and relapse. *The Angle Orthodontist*. *68*(1): 61-68.

Hotz, R. P. (1970). Guidance of eruption versus serial extraction. *American Journal of Orthodontics*, *58*(1): 1–20.

Jacobson, A., Miller, M.A. (2006). A cephalometric assessment of children treated with two serial extraction patterns followed by fixed orthodontic treatment. *American Journal of Orthodontics*, *129*(4): 590.

Joondeph, D.R., McNeill, R.W. (1971). Congenitally absent second premolars: an interceptive approach. *American Journal of Orthodontics*, *59*(1): 50-66.

Joondeph, D.R., Reidel R.A. (1976). Second premolar serial extraction. *American Journal of Orthodontics*, *69*(2): 169-184.

Kau, C. H., Miotti, F. A., and Harzer, W. (2004). Extractions as a form of interception in the developing dentition: a randomized controlled trial. *Journal of Orthodontics*, *31*(2): 107–114.

Kennedy, D. B. (2016). Strategies for managing missing second premolar teeth in the young patient. *Recognizing and correcting developing malocclusions: A problem-oriented approach to orthodontics* (eds E. A. Araújo and P. H. Buschang), 211-226, John Wiley & Sons.

Kjellgren, B. (1947). Serial extraction as a corrective procedure in dental orthopedic therapy. *Transactions of the European Orthodontic Society*, *8*(1):134-160.

Lagravere, M.O., Low, C., Flores-Mir, C., Chung, R., Carey, J.P., Heo, G., Major, P.W. (2010). Intraexaminer and interexaminer reliabilities of landmark identification on digitized lateral cephalograms and formatted 3-dimensional cone-beam computerized tomography images. *American Journal of Orthodontics and Dentofacial Orthopedics*, *137*(5): 598-604.

Lindqvist, B. (1980). Extraction of the deciduous second molar in hypodontia. *European Journal of Orthodontics, 2*(3): 173-181.

Little, R.M. (1987). The effects of eruption guidance and serial extraction on the developing dentition. *Pediatric Dentistry*, *9*(1): 65-70.

Little, R.M., Riedel, R.A., Engst, E.D. (1990). Serial extraction of first premolars — postretention evaluation of stability and relapse. *The Angle Orthodontist*, *60*(4): 255-262.

Lopes Filho, H., Maia, L.H., Lau, T.C.L., De Souza, M.M.G., Maia, L.C. (2015). Early vs. late orthodontic treatment of tooth crowding by first premolar extraction. *The Angle Orthodontist*, *85*(3); 510-517.

Mamopoulou, A., Hagg, U., Schroder, U., Hansen, K., Little, RM. (1996). Agenesis of mandibular second premolars. Spontaneous space closure after extraction therapy: a 4 year follow up. *European Journal of Orthodontics*, *18*(6): 589-600.

McReynolds, DC., Little, RM. (1991). Mandibular second premolar extraction – postretention evaluation of stability and relapse. *The Angle Orthodontist*, 61(2): 133-144.

O'Shaughnessy, K., Koroluk, L. D., Phillips, C., & Kennedy, D. B. (2011). Serial extractions versus late premolar extractions. *American Journal of Orthodontics and Dentofacial Orthopedics*, *139*(4): 510-516.

Papandreas, S.G., Buschang, P.H., Alexander, R.G., Kennedy, D.B., Koyama, I. (1993). Physiologic drift of the mandibular dentition following first premolar extractions. *The Angle Orthodontist*, *63*(2): 127-134.

Prosthodontics, A. O. (2017). The Glossary of Prosthodontic Terms, 9th edition. *The Journal of Prosthodontic Dentistry*, 117(5): C1, e1-e105. http://www.academyofprosthodontics.org/_Library/ap_articles_download/GPT9.pdf. Accessed 28 November 2017.

Proffit, W. R., Fields, H. W., Jr, and Sarver, D. M. (2012). *Contemporary Orthodontics.* 5th ed., Mosby, 463-470.

Ringenberg, Q. M. (1967). Influence of serial extraction on growth and development of the maxilla and mandible. *American Journal of Orthodontics*, *53*(1): 19-26.

Safaee, A., Mirbeigi, S., Haghani, J., Azimi, N. (2017). Assessment of correlation between chronological age and modified Demirjian estimated dental age. *Journal of Oral Health and Oral Epidemiology*, *6*(1): 14-21.

Simons, M. E., and Joondeph, D. R. (1973). Change in overbite: A ten-year postretention study. *American Journal of Orthodontics and Dentofacial Orthopedics*, *64*(4): 349–367.

Vaden, J. L., Dale, J. G., and Klontz, H. A. (2011). *Chapter 15: The Tweed-Merrifield Edgewise Appliance: Philosophy, Diagnosis and Treatment*. (eds T. M. Graber & R. I. Vanarsdall), 5th ed., Elsevier.

Wagner, M., and Berg, R. (2000). Serial Extraction or Premolar Extraction in the Permanent Dentition. *Journal of Orofacial Orthopedics*, *61*(3): 207–216.

Weber, A.D. (1969). A longitudinal analysis of premolar enucleation. *American Journal of Orthodontics*, *56*(4): 394-402.

Yoshihara, T., Matsumoto, Y., Suzuki, J., Sato, N., and Oguchi, H. (2000). Effect of serial extraction alone on crowding: Spontaneous changes in dentition after serial extraction. *American Journal of Orthodontics and Dentofacial Orthopedics*, *118*(6): 611–616.