

**KEYS TO CLASS II CORRECTION: A COMPARISON OF TWO
EXTRACTION PROTOCOLS**

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2018

Major Subject: Oral Biology

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ABSTRACT

Purpose: To evaluate the effects of two different extraction patterns on incisor and molar movements in growing Class II Division 1 patients.

Materials and Methods: The treated sample included 54 patients 10 to 17 years of age treated by two private practice orthodontists using Tweed mechanics, headgears, class II elastics or safe springs. The sample was divided based on having either the mandibular first premolars (4/4) or mandibular second premolars (4/5) extracted. Each group included 27 patients. Treatment lasted 2.8 ± 0.60 years and 2.6 ± 0.54 years for the 4/4 and 4/5 groups, respectively. Pre- and post-treatment lateral cephalograms and models were evaluated. Cranial base, mandibular and maxillary superimpositions were performed to quantify vertical and horizontal tooth movements and displacements.

Results: There were no statistically significant pre-treatment between-group differences in SNA, SNB, ANB, MPA, or crowding. There was statistically significant ($p < .05$) differences in pre-treatment IMPA, L1:NB, and L1:APo. Extraction of mandibular first premolars produced greater (1.6 mm) lower incisor retraction than extraction of second mandibular premolars. The mandibular first molar protracted significantly more (0.74 mm) when second premolars were extracted than when first premolars were extracted. The within-group changes in MPA, the between-group differences in the changes in MPA, and the amount of vertical eruption of the maxillary and mandibular molars were not significantly different between the two extraction patterns.

Conclusions: Extraction of lower second premolars enhances Class II correction. Compared to the first premolar extractions, mandibular second premolar extractions produce greater mesial movement of the mandibular first molar and less distal movement of the mandibular incisors. Neither first or second premolar extractions have an effect on the mandibular plane angle or the vertical dimension.

DEDICATION

This work is dedicated to my parents, Phyllis and Charles Sampognaro and Dan George, and my sister, Anna George Butler, for their constant love, encouragement, and support. Without the work ethic and drive my parents instilled in me, I would not have made it where I am now.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Peter Buschang, and my committee members, Dr. Phillip Campbell, Dr. Larry Tadlock, Dr. Emet Schneiderman, and Dr. Jim Boley for their guidance throughout the course of this research. I would also like to thank Dr. Jim Vaden and Dr. Jim Boley for making this research possible by allowing me to use their excellent patient records. I would like to thank my classmates and the department faculty and staff for contributing to such an outstanding educational experience.

NOMENCLATURE

U6	Maxillary First Molar
U1	Maxillary Incisor
U4	Maxillary First Premolar
L6	Mandibular First Molar
L1	Mandibular Incisor
L4	Mandibular First Premolar
L5	Mandibular Second Premolar
4/4	Maxillary First Premolar & Mandibular First Premolar
4/5	Maxillary First Premolar & Mandibular Second Premolar
Occl	Occlusal
Mes	Mesial
IMPA	Incisor Mandibular Plane Angle
MPA	Mandibular Plane Angle
L1:NB	Lower Incisor to Nasion & B point
L1:APo	Lower Incisor to A point & Pogonion
UTSALD	Maxillary Tooth Size Arch Length Discrepancy
LTSALD	Mandibular Tooth Size Arch Length Discrepancy
AP	Anteroposterior
SN	Sella to Nasion Plane

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Dr. Peter Buschang, Dr. Phillip Campbell, and Dr. Larry Tadlock in the Department of Orthodontics and Dr. Emit Schneiderman in the Department of Biomedical Sciences. The cases evaluated in this research were donated by Dr. Jim Vaden and Dr. Jim Boley. All other work conducted for this thesis was completed by Sarah George independently.

Funding Sources

This graduate study was supported by the Robert E. Gaylord Endowed Chair from the Baylor Oral Health Foundation.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Class II malocclusion is a common problem in the United States, affecting approximately 15% of the population.¹ Treatments for a Class II malocclusion include headgears, functional appliances, surgery, or orthodontic extractions. Over the years, orthodontics has made major advancements in the appliances and anchorage systems used, as well as in the understanding of growth and development. These advancements have allowed orthodontists to control growth and tooth movement in all three dimensions. With these developments, orthodontists now can offer a wider variety of treatment modalities. One of these includes different extraction patterns. Orthodontic extraction has been a controversial topic since the 1900s. Due to these major advances, orthodontists can use several different extraction patterns to achieve their treatment goals. Today, orthodontists use two extraction patterns when treating Class II Division I patients, including maxillary and mandibular first premolars (4/4) or maxillary first and mandibular second premolars (4/5). It has been established how these two extraction patterns affect the vertical dimension, but their effect on incisor and molar movement remains controversial.

The major reason for these inconsistent results of incisor and molar movement is due to the complexity of the study design. Most of the studies comparing 4/4 and 4/5 extraction patterns did not control for crowding, the vertical skeletal pattern, the

anteroposterior skeletal pattern, or molar occlusion. Also, the reference lines the studies are using to compare tooth movement are inconsistent and some are affected by growth as well as tooth movement. Moreover, several of the studies were biased because the patients' pre-treatment characteristics dictated the extraction pattern used which might be expected to offset results. Within and between study variability makes the results confusing and hard to apply to the clinical setting.

It is widely believed in the orthodontic community that extraction of mandibular first premolars will result in more incisor retraction and extraction of mandibular second premolars will result in more mandibular first molar mesial movement and less incisor retraction. However, these concepts are based largely on clinical observation and experience. Understanding incisor and molar movements is important because it explains a shift in the choice of extraction pattern when treating Class II Division I patients from extracting 4/4 to 4/5 patterns. In 1997, Dr. Phillip Campbell suggested extracting the mandibular second premolar to allow the mandibular first molar to move more mesially and aid in the Class II correction.²

The aim of the present study is to evaluate incisor and molar tooth movements in growing Class II Division I patients who either had 4/4 or 4/5 extraction patterns. To study tooth movement, efforts were made to ensure that the two samples were similar prior to treatment with both groups exhibiting mild to no crowding, normal range of vertical patterns, and the same anteroposterior skeletal and dental relationship. There is a need for more properly designed studies to evaluate tooth movements in Class I and Class II patients. It is expected the extraction of lower first premolars will result in

greater lower incisor retraction and the extraction of lower second premolars will result in more mesial movement of the lower first molar. It is time that research supports or negates this well-accepted concept of incisor and molar movements in these two extraction patterns so that orthodontists can provide evidence-based treatment to their patients.

Understanding the development of occlusion/malocclusion is crucial before one can proceed with correction. Knowledge of this concept allows the orthodontists to more properly diagnose and treat these malocclusions. This review will outline the development of occlusion, anteroposterior skeletal growth and dental pattern of Class II Division I patients and the development of hyperdivergent/hypodivergent skeletal facial patterns. Lastly it will discuss extractions as the treatment of Class II Division I patients sharing what the literature provides pertaining to profile changes, vertical changes, and tooth movements.

LITERATURE REVIEW

Classification of Occlusion/Malocclusion

The classification system for malocclusion that is used today was first developed in 1890 by Edward Angle, the father of modern orthodontics.³ This significant contribution provided the first simple and clear definition of normal occlusion, as well as the different types of malocclusion. Angle's classification is built on the maxillary first permanent molar and its relationship to the mandibular first permanent molar.³ Class I occlusion is based on the mesial buccal cusp of the maxillary first molar occluding in the

buccal groove of the mandibular first molar and on the mandibular line of occlusion aligning with the central fossa line of maxillary teeth.^{3,4} Any variation from this definition is considered a malocclusion. Angle used the maxillary first molar to define the following three types of malocclusions:

- *Class I malocclusion*: Normal anteroposterior relationship of the molars, but the line of occlusion is incorrect.³
- *Class II malocclusion*: mandibular first molar distally located relative to the maxillary molar.³
 - Division I: Maxillary anterior teeth proclined, large overjet
 - Division 2: Maxillary anterior teeth retroclined, deep overbite
- *Class III malocclusion*: mandibular first molar mesially located relative to the maxillary molar.³

Development of Occlusion

Normal dental development transitions between three distinct periods: the deciduous dentition, the mixed dentition, and the permanent dentition. The deciduous (primary) dentition is the first set of teeth to erupt into the edentulous arches. They begin to emerge during infancy. The mixed dentition comprises both the primary and permanent teeth. This stage begins when the permanent incisors erupt and replace the primary incisors, and the permanent first molars erupt distal to the second primary molars. The last period is the permanent dentition. It begins when the primary canines and molars are replaced by the permanent canines and premolars. It concludes with the eruption of the second and third molars.

Angel's classification is used to categorize the relationship of permanent teeth. The "terminal plane relationship" is used to classify the sagittal relationship of the primary dentition, specifically maxillary and mandibular primary second molars. The permanent molar relationship is initially determined by this terminal plane which guides the permanent molars into occlusion.⁵ Most children will exhibit an end-to-end or slight mesial step molar relationship in the deciduous dentition phase.^{6,7} Several investigators have characterized the distribution of molar relationships during the different periods of occlusal development using cross-sectional and longitudinal data.^{6,8-10}

Anterior-posterior molar relationships change between the deciduous and mixed dentition, and then again between the mixed and permanent dentition.⁸⁻¹⁰ Longitudinal studies have found that subjects in the mixed dentition with either a distal step or mesial step relation tend to maintain their relationship in the permanent dentition, while those with the flush terminal planes do not.^{8,9} For example, Arya, Savara, and Thomas showed that molars initially erupting into a distal or normal relationship continued to have a similar anteroposterior relationship in the permanent dentition.⁸ Of those patients whose molars initially erupted into a flush terminal relationship, about 70% developed a Class I molar relationship and the other 30% developed Class II molar relationships.⁸ Bishara et al in 1988 showed that subjects in the primary dentition with either a distal or mesial step relation maintained these anteroposterior occlusal relationships; but those with flush terminal planes, 56.3% progressed to a Class I molar relationship and 43.7% to a Class II molar relationship in the permanent dentition.⁹ The

changes in molar relationship have been explained in three different ways: early mesial shifts, late mesial shifts and differential mandibular growth.

Early Mesial Shift

The concept of “early mesial shift” was suggested by Baume in 1949 while studying 60 sets of serial dental casts and the physiological changes that occur. Baume found that two morphological arch forms (continuously spaced or continuously closed) were present in the deciduous dentition.⁵ Spaced dentitions presented in two distinct forms: a space between the mandibular primary canine and first primary molar or a space between the maxillary primary lateral incisor and primary canine.^{6,11} These spaces were called primate spaces.^{6,11}

According to Baume, an “early mesial shift” occurred when the lower deciduous molar moved mesially into the primate space as the permanent first molars erupted.^{5,6,12} Baume found that a denture base with a mandibular primate space and a flush terminal plane molar relationship could shift into a mesial step relationship (early mesial shift) as the mandibular primary molars migrated into the primate space when the permanent first molar erupted.^{5,6,12} Baume also noted that dental arches without spaces and a flush terminal plane relation resulted in end-to-end relationships of the first permanent molars.^{5,6,12}

In 1951, Clinch countered Baume’s idea of the early mesial shift. He studied 61 serial dental casts from the deciduous dentition until the eruption of the permanent incisors and molars. Clinch argued that the mandibular primate space was resolved from the distal movement of the primary canines when the larger mandibular permanent

incisors erupted.⁷ Cinch believed growth was the reason for the mesial movement of the mandibular primary and permanent molars.⁷

The idea of an early mesial shift is problematic because there is greater generalized spacing in the deciduous maxillary dentition than the deciduous mandibular dentition, suggesting that Class I molar relationships could not be obtained by early space closure.^{13,14} Moreover, the mandibular primate space is inadequate for Class I molar correction because it is limited and potentially completely resolved by the eruption of the mandibular permanent canines.^{7,13,14}

Late Mesial Shift

The “late mesial shift” has also been proposed as an explanation for the changes in molar relationships that occur. The “late mesial shift” occurs when the upper and lower molars shift mesially into the leeway space. The leeway space is the difference in the mesial-distal width of the primary canines, first and second molars, and their permanent replacements. After the incisors are aligned the leeway space is approximately 1.2 mm in the maxilla and 2.2 mm in the mandible per side.^{14,15} Since there is a larger leeway space in the mandible, a flush terminal plane could correct to a Class I relationship by the mandibular molar sliding forward more than the maxillary molar after the primary second molars exfoliate.^{5,6,12,14}

The concept of the late mesial shift has also been contradicted. Studies have found that there is no relation between the final molar relationships and the difference in maxillary and mandibular leeway spaces.¹⁶⁻¹⁹ The difference in leeway space in the maxilla and mandible is approximately 1 mm; which is insufficient to correct a ½ step

Class II molar relationship to a Class I molar relationship. Studies have also shown that the maxillary first molar mesial movement exceeds that of the mandibular permanent molar during the transition from mixed to permanent dentition.¹⁶⁻²⁰ The greater mesial movement of the maxillary molar compared to the mandibular molar will have a negative effect on the amount of Class II correction.

Differential Jaw Growth and Dentoalveolar Compensations

Historically, researchers evaluated serial dental casts to study the tooth movement that occurred between the deciduous and permanent dentition. Studying dental casts allows tooth movement to be assessed, but it does not permit skeletal growth to be analyzed. Dental casts do not allow the skeletal and dental components contributing to the changes in the occlusal relationship to be differentiated. More recently cephalometric studies have been performed to evaluate the contributions of skeletal growth and tooth movement in the development of occlusion.^{16-19,21} Cephalometric studies using superimpositions allow the dental and skeletal components to be examined and tooth movement and skeletal growth to be differentiated and quantified. Cephalometric studies have concluded that differential mandibular growth offers the best explanation for the changing molar relationships.^{16-18,21}

Based on these cephalometric studies, differential jaw growth seems to provide the best explanation for the changing molar relationship during the transitional dentition.^{16,17,19,21} In 1983, White examined a sample of 24 subjects who had an end to end molar occlusion in the early mixed dentition and followed them into the permanent dentition.¹⁹ White found that subjects who developed a Class I molar relationship had

significantly greater mandibular than maxilla growth compared to those who did not develop a Class I molar relationship.¹⁹ Kim et al studied serial cephalograms from 40 patients beginning in the early transitional dentition and extending to the permanent dentition.¹⁶ The sample was divided into three groups based on the long-term growth pattern: in one group the mandible outgrew the maxilla, in another group the both jaws grew about the same, and in the third group the maxilla outgrew the mandible. The cephalometric findings showed that growth differences between the maxilla and mandible greatly influenced the changes in the molar relationship during the transitional dentition, and the amount of physiologic mesial shift.¹⁶ Once the patients reached the permanent dentition, the skeletal growth differences no longer affected the molar relationships because they were largely absorbed by dentoalveolar compensations.¹⁶ Dentoalveolar compensation occurs when the dental and alveolar arches adjust to maintain the occlusion.²² For example, when the mandible grew more than the maxilla, the mesial displacement of the maxillary first molar negated the sagittal growth difference.¹⁶ When the maxilla grew significantly more than the mandible, the mesial displacement of the mandibular molar negated the sagittal growth difference.¹⁶

Tsourakis & Johnston evaluated the relative contributions of skeletal growth and tooth movement in 39 untreated growing patients following them from the deciduous dentition into their first molar adjustments of the permanent dentition.²¹ The sample was divided based on having mesial step, distal step, and flush terminal plane relationships. The flush terminal plane was divided further based on final molar relations: Class I, end to end, or Class II. Skeletal and dental changes were measured from yearly regional

superimpositions. They found that patients with a mesial step primary dentition tended to develop a Class I relation, and patients with a distal step primary dentitions tended to develop a Class II relation.²¹ Variability was found in patients with a flush terminal plane primary dentition, which could be explained by the timing of mandibular growth and the upper molar mesial drift.²¹ For example, those with flush terminal planes who developed Class II molar relationships had slower rates of the mandibular growth from 5-11 years of age than those who developed Class I relationships.²¹ Also, the mesial movement of the upper molars were consistently greater in the flush terminal plane that developed a Class II relationship.²¹

In 1991, Harris et al studied Class II Division 1 adolescent and adult patients treated with four premolar extractions to evaluate how the Class II malocclusion was corrected.²³ They found that differential mandibular growth accounted for approximately 70% of the molar correction in adolescent patients, with 30% of the correction resulting from orthodontic tooth movement.²³ In adolescents the mandible grew anteriorly 4.1 mm compared to the maxilla which was displaced anteriorly 1.7 mm; the net apical base difference was 2.5 mm.²³ In adolescents both the maxillary and mandibular molars translated forward, but the net change was 1.1 mm mesial movement of the mandibular molar.²³ In adults, the forward maxillary growth (average 0.7 mm) negated the correction because the mandible remained stable; therefore, mandibular dental movement accounted for 120% of the correction.²³

Class II Division I Patients

Definition and Prevalence

A class II malocclusion occurs when the mandibular molar is distally positioned relative to the maxillary molar and is a common problem occurring in approximately 15% of the U.S. population.¹ An Angle Class II malocclusion characterized by an overjet of 5 mm or more is found in approximately 23% of children (age 8-11 yrs.), 15% of youths (age 12-17 yrs.), and 13% of adults (age 18-50 yrs.).^{1,3} The National Center for Health Statistic reported that approximately 14.5% of 12 to 17 years old have bilateral Class II molar relationships. Most class II dental malocclusions are due to skeletal discrepancies, with approximately 75% of patients with Class II dental malocclusion also having a Class II skeletal relationship.^{24,25}

Growth and Development

Knowledge of Class II skeletal growth helps in understanding the etiology of the malocclusion and potential ways of correcting it. Class II malocclusion is due to mandibular deficiencies and a retrusive chin position.²⁶ It has now been established that a Class II malocclusion develops primarily as a result of mandibular retrusion rather than maxillary prognathism.²⁷⁻²⁹ Class II subjects also exhibit a shorter mandibular length and ramus heights than Class I subjects.²⁷⁻³⁰ These malocclusions can be detected early, when the patient is in primary dentition, and they do not appear to be self-correcting without orthodontic treatment.²⁷⁻³⁰

Buschang and Jacob studied 130 French Canadian untreated adolescents with Class I and Class II malocclusions to determine differences in mandibular growth and modeling

between the two classes.²⁹ The ANB angle was significantly smaller in the Class I's at 10 and 15 years of age.²⁹ These differences were mainly due to a retrusive mandible (differences in SNB), with the maxillary position showing no difference between groups.²⁹ Class IIs had SNB angles that were approximately 2° smaller than Class I's at age 10 and 2.5° smaller at age 15.²⁹ Class II patients had significantly smaller mandibular lengths (CoGn) at 15 years of age than Class Is and a smaller ramus height.²⁹ They also had less total and vertical adolescent condylar growth during adolescence than Class Is.²⁹

Stahl et al compared the growth changes of untreated Class IIs and Class Is using the cervical vertebral maturation method.²⁷ At the initial observation, Class II subjects were found to have a significantly more retruded mandible relative to the cranial base and a significantly greater sagittal jaw discrepancy (Wits, ANB, maxillomandibular differential) when compared to Class Is.²⁷ At the end of the observation period, the total mandibular length (CoGn) was significantly shorter in Class II subjects than Class Is.²⁷ During the adolescent growth spurt (CS3-CS4), the Class II sample had a significantly smaller increase in total mandibular length (-2.0mm).²⁷ During the adolescent growth spurt, the Class II sample had smaller (by 2.9 mm) increases in total mandibular length (CoGn) and smaller increases in mandibular ramus height (CoGo) (by -1.5mm) than Class I subjects.²⁷ The smaller increases in mandibular length resulted in a smaller increase in the maxillomandibular differential (-1.7mm) in the Class II group.²⁷ The Class II subjects showed deficient mandibular growth during the growth spurt, and this

deficiency was maintained at the postpubertal observation showing that the skeletal disharmony did not self-correct over time.²⁷

Buschang et al showed deficiencies in growth rates in children with Class II malocclusions resulting in approximately 0.2 mm/yr. to 0.4 mm/yr. less growth for children with normal occlusion.³¹ These deficiencies accumulate and produce significant differences at older ages.³¹

Hypodivergent/Normodivergent

It is also important to realize that both the growth displacements and tooth movements that occur can be affected by the vertical divergence in jaw growth of patients. Clinically, it is necessary to distinguish between hyperdivergent and hypodivergent Class II patients because this will affect tooth movement and growth, both anteroposteriorly and vertically.

Research has shown that on average hypo-, normo-, and hyperdivergent untreated patients will show forward rotation as they age.³²⁻³⁵ The majority of untreated patients will maintain their vertical facial pattern as they grow.^{36,37} Untreated hypodivergent patients have significantly more forward rotation than untreated hyperdivergent patients.³³

As previously indicated, approximately 25% of Class II patients have a Class II dental relationship and are skeletally Class I normal growers.^{24,25} In addition, approximately 2-5% of Class II patients are Class II Division 2 patients.³⁸ Several studies have shown that most of Class II Division 2 patients are hypodivergent and good growers.³⁹⁻⁴¹ A longitudinal study in 2012 by Barbosa compared the growth of

untreated Class II Div. 2 patients to that of Class I patients. The results showed that the Class II Div. 2 patients had smaller MPAs, smaller gonial angles, and more horizontal growth patterns compared to Class I patients.⁴¹ In conclusion, about 50% of all Class II patients are hypodivergent and good growers. Growth can be important when correcting a Class II dental and skeletal relationship.

Hyperdivergent

Class II malocclusion occurs in about 15% of the population and approximately half of these subjects, or about 7-8% of the total population, are both retrognathic and hyperdivergent.⁴² In 1964, Schudy first introduced the term “facial divergence” and defined the two extreme divergence patterns as “hyperdivergent” and “hypodivergent.”⁴³ Facial pattern is established at a very young age. S.K. Nanda studied 32 patients between 3-18 years of age with either a skeletal open bite or skeletal deep bite to determine the patterns of vertical development.⁴⁴ He found that the vertical developmental patterns were established around six years of age, before the eruption of the permanent dentition, and maintained this pattern throughout growth.⁴⁴ Nanda’s results suggested that young patients with a longer lower anterior face had end-on Class II relationships of the lower second primary molars.⁴⁴ These patients may not develop a normal interdigitation of molars, whereas a person with a shorter lower anterior face height may display greater horizontal growth which could help the development of normal interdigitation.⁴⁴

The average pretreatment mandibular plane angle for Class II subjects has been documented to be similar to Class I subjects.⁴² The literature has reported that children

with a Class II molar relationships show a slightly (but not statistically significant) greater tendency toward hyperdivergence than Class I subjects, and that those subjects whose anteroposterior discrepancies increased the greatest over time were more likely to show the greatest increases in their vertical discrepancy as well.^{42,45,46}

There are reliable differences between Class I subjects when compared to hyperdivergent retrognathic patients.⁴² The maxillary characteristics of hyperdivergent subjects depend on whether the malocclusions were defined on dental or skeletal criterion. The literature reveals that most of the hyperdivergent subjects' maxillary features are the result of a dentoalveolar problem rather than a skeletal problem.^{42,47,48} Studies consistently show that the anterior and posterior dentoalveolar heights are increased in hyperdivergent patients.^{42,47}

The mandible of untreated hyperdivergent patients shows more pronounced and greater differences than the maxilla.⁴² Hyperdivergent patients have greater anterior face height, a smaller ramus height, a larger gonial angle, excessive posterior dentoalveolar heights, a retrognathic mandible, and a steeper mandibular plane angle.^{42,47,49-54} Skeletal discrepancies for hyperdivergent patients improve less over time, with their MPA decreasing only 0.3° between ages 6-15 years of age, compared to a decrease of 2.5° and 4.0° for average and hypodivergent subjects, respectively.⁴² The SNB angle increases only 0.2° in hyperdivergent subjects compared with 1.2° and 1.4° for average and hypodivergent subjects, respectively.⁴²

Treatment

It is widely accepted among orthodontists that treatment objectives/plans revolve around facial esthetics (including the sagittal position of the anterior teeth), function, health, and stability. The correction of a Class II malocclusion is dictated by the orthodontists' understanding of the malocclusion, the possibilities of tooth movements, and the effect of growth on treatment. There are currently three approaches for treating Class II skeletal and/or dental malocclusions including growth modifications, orthodontic camouflage, or surgery. Common non-surgical treatment approaches include headgear, functional appliances, distalization, and extractions. The proper diagnosis is key to determine the correct treatment modality. Extractions is one of the common treatment options for correcting a Class II malocclusion.

History of Extractions

One of the crucial decisions made in orthodontic treatment planning, not including the decision to provide treatment or no treatment, is whether extractions are necessary.^{55,56} Clinicians' perspectives concerning extractions have varied historically. Angle, the father of orthodontics, believed that in an ideal Class I molar occlusion all thirty two teeth could be accommodated in the jaws.⁵⁷ Extractions contradicted his belief, as he thought bone would develop around the teeth in their new location.⁵⁷ Calvin Case, however, disputed this idea saying that extractions were needed to relieve crowding and maintain stability.⁵⁶ Charles H. Tweed, a graduate of the Angle Course, worked alongside Angle until his death and carried out his principle of never extracting teeth. Based on the post treatment facial esthetics of his patients, Tweed became very

discouraged.⁴ He devoted four years to studying the success and failures of his cases and determined that upright mandibular incisors related to both post-treatment facial esthetics and stability.⁴ He concluded that in order to achieve upright mandibular incisors, extraction of teeth and preparation of anchorage were often needed.^{4,58} One of the many contributions that Tweed made to orthodontics was making the extraction of teeth for orthodontic correction acceptable.⁵⁹

Premolars are the most frequently extracted teeth in orthodontic treatment due to their location in the dental arches.⁶⁰ Historically, the teeth most commonly extracted for orthodontic treatment were the four first premolars.⁶¹ In 1949, Nance was one of the first to promote an alternative extraction sequence; maxillary and mandibular second premolars or second premolars from one arch and first premolars from the other arch.⁶¹ In 1964, Schoppe rationalized that since there are different types and severity of orthodontics cases, the treatment plans and appliances should vary as well.⁶² He concluded that second premolars should be extracted if the TSALD was less than 7.5 mm and there was no need for incisor retraction.⁶² It is evident that orthodontic treatment has progressed over time, leading to techniques that have greatly improved the profession's ability to control the movement of teeth in all three planes of space. Currently a variety of extraction patterns exist due to the advances in orthodontic therapy, the professions' understanding of growth and development, and how tooth movements correspond with anticipated facial growth changes.⁶³

Extraction vs Non-Extraction

The main controversy regarding extractions pertains to the perception that extractions have a negative effect on the profile causing a “flattened” or a “dished in” appearance. Research has shown that patients with extractions do have a straighter profile at the end of treatment compared to non-extraction patients; but dentists and laypeople favor these straighter profiles.^{64,65} Although these profiles tend to be “flatter” on average, it does not necessarily correlate to an unaesthetic outcome. Bishara and Jakobsen, presented pretreatment and posttreatment profile silhouettes of extraction and non-extraction patients to the public and found that neither group was favored over the other.⁶⁴ Long term evaluations have shown that regardless of the treatment modality (extraction or non-extraction), the continuing soft tissue profile changes are not affected.^{66,67}

As with any treatment plan the proper diagnosis needs to be obtained to determine if extractions are necessary during treatment. In 1975, Brandt and Safirstein stated that the decision to extract teeth should be influenced by the type of malocclusion, the growth pattern of the patient, the condition of the teeth, and the health of the periodontal supporting tissue as well as the clinicians’ treatment objectives.⁶³ Bishara et al found that, with respect to Class II Division I malocclusion, the decision to extract is based primarily on the amount of tooth size-arch length discrepancy and the amount of lip protrusion.^{63,64,68} Different extraction patterns such as U/L 4s, U/L 5s, and U4/L5s have been evaluated to determine their effect on soft tissue profile change, incisor

retraction, facial vertical dimension, and maxillary and mandibular arch dimensional changes.⁶⁹⁻⁷⁵

Extractions and Profile

An esthetically pleasing outcome is of major importance in orthodontic treatment. It has been established that a detailed assessment of the facial profile should be considered when diagnosing and treatment planning an orthodontic case.⁷⁶ Facial profile is determined not only by the natural morphology of the soft tissue but also the underlying skeleton and the positions and angulations of teeth. It has been established that facial esthetics will not be compromised post treatment if extractions are based on sound diagnostic criteria.^{64,66,77}

Several studies have evaluated profile changes of extraction and nonextraction cases; but very few have evaluated the effects of different extraction patterns. Wholley and Woods evaluated the effects of extraction patterns on the facial profile and the curvatures of the upper and lower lips.⁷³ They found that regardless of the extraction sequence, the upper and lower lips showed similar changes in the depths of lip curvature with a wide range of individual variation resulting from skeletal, dental, and soft tissue factors.⁷³ Based on this study the orthodontist can protect the facial profile regardless of which teeth are extracted if the spaces are properly managed. Similarly, Steyn et al reported that the decision of which premolars to extract would eventually be of little significance to the overall soft tissue facial appearance of that patient.⁷²

A systematic review was conducted to evaluate the cephalometric soft tissue changes after orthodontic treatment in Class II malocclusions in patients treated with

either two or four premolar extractions.⁷⁴ Based on 13 articles, the study found that there is a significant increase in nasiolabial angle ranging from 2.4 to 5.4 degrees with extraction of two premolars and a 1.0 to 6.8 degree increase when extracting four premolars.⁷⁴ While both lips are retracted with two and four premolar extractions, less lower lip retraction occurs than with two maxillary premolar extractions.⁷⁴

Extractions and Vertical Pattern

Because the vertical dimension affects facial proportions it must be addressed and controlled to minimize the harmful effects of unfavorable growth patterns. One idea hypothesized to control the vertical dimension is known as the “wedge effect” which is still controversial today. This concept began around the 1960-70s, when mandibular growth and rotation were being introduced and researchers were studying the relationship between facial skeletal growth patterns and dental occlusion.^{32,78} According to the “wedge effect”, the extraction of premolars allows the molars to move mesially into the extraction space permitting the mandible to rotate counterclockwise and reduce the vertical dimension.⁷⁸ In 1972, Nasby and coworkers recommended extractions in high angle patients to decrease the anterior facial height and upright the incisors to close the bite.⁷⁸ Literature has shown that there are no significant differences in the vertical dimension between extraction and non-extraction treatment groups; both groups show increases in vertical dimension over time.⁷⁹⁻⁸²

For example, Staggers compared changes in vertical dimension of Class I patients treated orthodontically with 4/4 extractions to Class I patients receiving non-extraction treatment.⁸⁰ Seven cephalometric measurements (MP-HP, N-Me, N-

ANS/ANS-Me, G-Me', G-SN/SN-Me', U6-PP, L6-MP) were evaluated.⁸⁰ The pretreatment values were subtracted from the post-treatment values to acquire the changes produced.⁸⁰ Stagger found no significant differences in the changes that occurred between the extraction and non-extraction treatment groups.⁸⁰ All of the cephalometric measurements reflected an increase in the vertical dimension from pre-treatment to post-treatment.⁸⁰

Studies have also compared the most common premolar extraction patterns and how they affect the vertical dimension.^{69,72,83-85} Kim et al compared the mesial movement of molars and changes in facial vertical dimensions in Class I hyperdivergent (FMA>24° or SN-GoGn >32°) patients treated with 4/4 extractions or 5/5 extractions.⁶⁹ There were 27 patients in each group. The study excluded extra-oral appliances that would extrude the molars, elastics, and expanders.⁶⁹ Fourteen angular, seven linear, and seven proportional measurements were used to evaluate vertical dimensional changes.⁶⁹ Superimpositions were performed to evaluate molar movement and changes in vertical dimension. The 5/5 extraction group showed more mesial movement of the maxillary and mandibular molars and less retraction of the incisors.⁶⁹ Both extraction groups showed that facial height measurements (AFH, PFH, UAFH, LAFH, TFH) significantly increased after treatment.⁶⁹ When comparing the amount of vertical change between the two extraction groups, there were no significant differences in any of the linear or proportional measurement; however, there were significant difference in the SN-PP and maxillomandibular plane angle, but they were too small to have any clinical significance.⁶⁹

Al-Nimri evaluated Class II Division I patients who required 4/4 extractions or 4/5 extractions and compared the changes in the vertical dimension.⁸³ There were 26 subjects in each group matched by sex, age, and facial divergence. The study excluded headgear and functional appliances. The amount of Class II elastic use and the duration of the reverse curve of spee arch wire in the lower arch were not significantly different between the two groups.⁸³ Initially the 4/5 group had less crowding and more overjet than the 4/4 group.⁸³ Results showed that the mandibular molars were protracted significantly more in the 4/5 group (4.7 mm) than in the 4/4 group (2.9 mm).⁸³ In both groups there were significant increases in TAFH, LAFH, and PFH; but there was no significant difference in vertical facial growth between the two groups.⁸³ The LAFH increased 4.2 mm in the 4/4 group and increased 3.8 mm in the 4/5 group, but the difference was not statistically significant.⁸³ Neither group showed significant within-group changes in the MPA or the maxillomandibular plane angle.⁸³

Wang et al studied 47 patients with a Class I malocclusion who required 4/4 and 4/5 extractions and found that the facial height (LAFH, PFH, LAFH:TAFH, PFH:AFH) was increased after treatment but this increase was not statistically different between the two groups.⁸⁴ Wang did however find a significant difference in the change in the MPA with the 4/4 group's MPA decreasing and the 4/5 groups MPA increasing.⁸⁴ Steyn et al also studied 73 Class I patients and found the facial divergence unaffected in both the 4/4 and 4/5 extraction groups; with both groups having an increase of 0.8% in facial divergence.⁷² These results also do not support the wedge effect. As of now there is no current literature that supports the wedge effect. The results show that regardless of the

extraction pattern, there will be no significant differences in the vertical dimension.^{69,72,83,84}

Extractions and Tooth Movement

Different extraction patterns have been compared to quantify molar movements and incisor retractions.^{70-72,75,85} The studies are particularly difficult to compare due to differences in pretreatment characteristics within a study and overall variation between studies. Initial pretreatment characteristics such as initial overjet, severity of crowding, molar relationship, and vertical skeletal pattern can result in a wide range of individual variations in tooth movements.^{70,71,75} The designs and reference line used are also different in each study, which makes interpretation of the results confusing and inconsistent.⁷²

Chen et al performed a retrospective study evaluating the positional changes of the incisors and molars after extraction of four second premolars in Class I subjects with mild crowding and mild dental protrusion.⁸⁵ They found that the incisors moved lingually approximately 3.3 mm in the maxilla and 2.9 mm in the mandible, and the first molars moved mesially an average of 3.2 mm in the maxilla and 3.4 mm in the mandible.⁸⁵ The results showed that the extraction space was closed by moving the anterior and posterior segments almost equally; incisor retraction accounted for approximately 50.4% of space closure in the maxilla and 46.2% in the mandible.⁸⁵ Chen et al also found no significant differences in the vertical parameters measured except for the extrusion of the lower molar.⁸⁵

Shearn and Woods evaluated cephalograms and arch dimensional changes that occurred from various extraction patterns (mandibular first or second premolars).⁷¹ The amount of incisor retraction that occurred was based on a mandibular superimposition along the corpus axis registered at suprapogonion.⁷¹ The pterygomaxillary (PM) vertical line was used as a reference and the incisal changes were measured perpendicular to the reference plane.⁷¹ The results showed no significant difference in the amount of lower incisor retraction among the groups.⁷¹ There was a wide range of individual variation in each group, but there was a tendency for greater lower incisor retraction with extraction of lower first premolars than with lower second premolars.⁷¹ Mean incisor retraction relative the A point to Pogonion (APog) line also showed no statistically significant between-group differences ($P=0.07$).⁷¹ Incisor retraction in the 4/4 group was 2.4 mm, while the mean was 1.4 mm in the 4/5 group and 0.50 mm in the 5/5 group.⁷¹ Shearn and Woods estimated lower molar protraction based on arch depth changes and incisor positional changes measured on the superimposition. The results showed no significant difference in the amount of forward movement of the lower molar, which ranged from 4 to 4.5 mm regardless of which premolar was extracted.⁷¹ A major problem in this study was the amount of individual variation in tooth movements. The population selected in this study had considerable differences in pretreatment characteristics. Pretreatment factors such as crowding, overjet, molar relation and facial vertical pattern affected which extraction sequence for the patient which introduces biases. The APog reference line used to measure incisor retraction can be affected by growth, the anteroposterior and vertical movement of the chin, and any treatment effect at A point. Other problems

included a small sample size for the 4/4 group and the mandibular second premolar extractions included patients with either first or second maxillary premolars extracted which could have affected the results.

Ong and Woods specifically looked at the dimensional changes of the maxillary arch with the extraction of either first or second premolars.⁷⁰ The amount of incisor retraction was measured with the maxilla superimposed on the palatal plane.⁷⁰ The pterygomaxillary (PM) vertical line was used as a reference line, and incisal changes were measured perpendicular to the reference plane.⁷⁰ Based on the superimposition, there was a statistically significant difference in the mean incisor retraction among uppers 4s and upper 5s.⁷⁰ The extraction of upper 4s retracted the incisors 2.5 mm and extraction of upper 5s retracted the incisors 1.6 mm.⁷⁰ Upper incisor position and angulation changes were also measured relative to the A point to Pogonion (APog) line. Relative to the APog line, there was a significantly larger mean retraction of the upper incisors in both the 4/4 and 4/5 groups compared to the 5/5 extraction group.⁷⁰ Incisor retraction was 4.2 mm in the 4/4 group, 3.7 mm in the 4/5 group and 2.3 mm in the 5/5 group.⁷⁰ Similar results were noted in maxillary incisor angulation relative to the APog line and the palatal plane (PP), with a significant reduction when maxillary first premolars (APog=8.2°, PP= 5.0°) were extracted compared to maxillary second premolars (APog=3.3°, PP=1.6°).⁷⁰ Ong and Woods also estimated upper molar protraction from arch depth changes and incisor position changes measured on the superimposition. The mean changes in mesial maxillary molar movement were not significantly different among the extraction groups.⁷⁰ The problems in this study were

similar to those found in the Shearn and Woods study. The sample started out with pre-treatment differences and the extraction patterns were based on crowding, incisor position, and Class II molar relationship. Also, the sample size for the 4/4 group was much smaller than for the other extraction groups. Moreover, certain variables biased the amount of incisor retraction. For example, there was greater retraction of the incisors in cases with less crowding. Due to this wide range of individual variation in maxillary incisor retraction, using the mean values as estimates for all patients may be difficult.

Steyn et al, who evaluated maxillary and mandibular incisor retraction relative to the N-Pog line, found that the maxillary incisors were retracted 4.2 mm and 4.7 mm when extracting 5/5 and 4/4 respectively, and 6.6 mm from N-Pog in the 4/5 group.⁷² The lower incisors were retracted more in the 4/4 group (2.1 mm) than in the 5/5 (1.3 mm) and the 4/5 (1.4 mm) groups.⁷² Steyn also did not find any significant difference in facial divergence among the three groups.⁷² In this study, there was no mention of the statistics used making it difficult to know how the authors derived these conclusions. A problem in this study was the sample population was not homogenous, extractions were prescribed based on pre-treatment characteristics. The sample characteristics were not well defined; there were no mention of samples ANB, MPA, SNB, age, or molar classifications. There were also no p-values given to determine if extraction groups differed pre-treatment. The references line used to measure tooth movements could be affected by growth and treatment which could potentially affect the results. Wang et al also studied 93 growing patients with a Class I malocclusion who had either 4/4 and 4/5

extractions and measured incisor and molar tooth movements relative to the pterygomaxillary reference line on a lateral cephalogram.⁸⁴ Neither the amount of incisor retraction nor molar protraction was significantly different between the two extraction groups.⁸⁴ In the 4/5 group the lower incisors were retracted 1.65 mm and the molars protracted 4.55 mm and in the 4/4 group the lower incisors were retracted 1.07 mm and the molars protracted 4.08 mm.⁸⁴ However, Wang et al studied total tooth movement from both displacement and migration which could potentially affect the results especially when the sample includes growing patients.

Al-Nimri evaluated Class II Division I patients treated with premolar extraction, where lower incisor retraction was not a treatment objective.⁷⁵ Al-Nimri reported that only 65% of patients in the study had mandibular incisors retracted, and the average change in mandibular incisors relative to N-Pog line was 1.3 mm when first premolars were extracted and 0.8 mm when second premolars were extracted; but this difference was not significantly different.⁷⁵ In another article, Al-Nimri studied molar protraction in 52 Class II division I growing patients with 4/4 and 4/5 extractions.⁸³ Al-Nimiri found a significant difference in the amount of molar protraction measured off a mandibular superimposition. The mandibular molars were protracted 2.9 mm in the 4/4 group and 4.7 mm in the 4/5 group.⁸³ A problem with this study is the two extraction groups differed pre-treatment. The two groups differed in overjet and residual space. Also, the superimposition used to evaluate tooth movement was not based on stable structures.

William and Hosila also evaluated the amount of incisor retraction with different extraction patterns, including upper and lower first premolars, upper first and lower second premolars, upper and lower first molars, and upper and lower first premolars and molars.⁸⁶ These cases were treated using the Begg technique.⁸⁶ Incisor retraction was measured using the palatal anatomy as a reference plane.⁸⁶ They found that the total amount of upper and lower incisor retraction is about 10.3 +/-4.5 mm when extracting four first premolars whereas upper first and lower second premolars had about 9.3 +/- 3.7 mm of incisor retraction.⁸⁶ The results concluded that the anterior segment occupied about 66.5% of the extraction site when four first premolars were extracted and about 56.3% when upper first premolars and lower second premolars were extracted.⁸⁶

It is difficult to quantify the exact amount of incisor retraction and molar mesial migration in different extraction patterns due to the high degree of variability that exists among patients and study designs. Based on the studies reviewed, the only significant difference related to the extraction patterns was the amount of upper incisor retraction, which again was highly variable. In most of these studies, a substantial amount of individual variation was noted in response to the orthodontic treatment regardless of the extraction pattern. Extraction sequences are not the only factors that can affect tooth movements. Tooth movements can also vary due to pretreatment characteristics (crowding/spacing), growth, treatment mechanics/anchorage, and treatment objectives. This all needs to be taken into consideration when predicting the amount of incisor retraction or molar protraction. With the current understanding of biomechanics,

orthodontic tooth movement and new anchorage devices it is possible to control the amount of incisor and molar movements with each extraction pattern.

The problem with the studies that evaluated the amount of molar tooth movement was that they neglected to look at the contribution of growth. Several studies used mandibular or maxillary casts to estimate the amount of mesial molar movement.^{70,71} The amount of movement measured on a cast represents both molar movement from growth displacement and tooth migration.^{70,71} Chen et al used maxillary and mandibular superimpositions to evaluate molar tooth movements, but did not factor in the role of growth displacement.⁸⁵ When considering various extraction patterns, it is important to not only consider the tooth movements, but it is also important to consider growth because this can affect the overall tooth movements.

It is also important when evaluating different extraction patterns that a homogenous sample is used. Skeletal patterns can affect the horizontal movement of the tooth. In the current study, it will be important not only to consider tooth movements in relation to the jaws, but to also consider the amount and type of growth the patients undergo.

Conclusion

There is currently no conclusive evidence on which extraction pattern produces more incisor retraction or molar protraction; or if one extraction is more appropriate for correcting a Class II malocclusion. This study will attempt to clarify what tooth movements are most likely expected from each extraction pattern and provide evidence for concepts that were largely based on clinical observation and experience. The

resulting information will provide understanding of what tooth movements are expected in each extraction pattern, and how it is beneficial in correcting a Class II malocclusion. These results could prove that certain extractions patterns will achieve a Class II correction more predictably. With this knowledge, orthodontists will be able to more appropriately select a specific extraction pattern based on the movements expected from each and more specifically select an extraction pattern appropriate for Class II patients to correct the malocclusion.

CHAPTER II
KEYS TO CLASS II CORRECTION: A COMPARISON OF TWO
EXTRACTION PROTOCOLS

INTRODUCTION

Class II malocclusion is a common problem, affecting approximately 15% of the US population.¹ This form of malocclusion can be treated in a variety of ways including headgears, functional appliances, surgery, and extractions. Advances in the appliances and anchorage systems used, as well as in the understanding of growth and development, have made it possible for orthodontists to better control tooth movement in all three dimensions, using a variety of treatment modalities. Today, orthodontists primarily use two extractions patterns when treating Class II Division 1 patients, including maxillary and mandibular first premolars (4/4) or maxillary first and mandibular second premolars (4/5). While the effects of these two extraction patterns on the vertical dimension have been established,^{72,83,84} their effects on incisor and molar movement remain controversial.

It was originally thought that the vertical dimension can be better controlled with the extraction of the lower second than first premolars. This idea is based on the “wedge effect”, where the lower first molars move more mesially and decrease the vertical dimension by “closing down the wedge”. However, no differences have been reported between the 4/4 and 4/5 extraction in the facial vertical dimension.^{72,83,84} Al-Nimri, studying patients with a Class II Division I malocclusion, reported essentially the same

amounts of vertical facial growth and the same changes in mandibular plane angle among the two extraction patterns.⁸³ Steyn and coworkers, who evaluated Class I patients, found that facial divergence was virtually unaffected with either extraction pattern.⁷² Wang et al, who also studied Class I patients, reported vertical changes after orthodontic treatment, but no notable differences between groups.⁸⁴

The orthodontic community believes that extraction of mandibular first premolars will result in more incisor retraction and the extraction of mandibular second premolars will result in more mandibular first molar mesial movement. However, these concepts are based largely on clinical observation and experience. Understanding incisor and molar movements is important because it explains a shift in the choice of extraction patterns when treating Class II Division I patients, from extracting 4/4 to 4/5 patterns. In 1978, Campbell suggested extracting the mandibular second premolar to allow the mandibular first molar to move more mesially, and aid in the Class II correction.² Currently, there is no consistent evidence regarding the incisor and molar movements when either first or second mandibular premolars are extracted.

The literature evaluating incisor movement associated with these two extraction patterns is controversial, with three of four studies finding no differences.^{71,72,75,84} Steyn et al, who studied Class I patients, found that the lower incisors were retracted significantly more in the 4/4 group compared to the 4/5 group.⁷² However, this study was subject to selection biases, the extraction patterns were determined by the patients' pre-treatment characteristics, and the reference lines used to measure incisor movement (nasion and nasion to pogonion) could be affected by growth and treatment.⁷² Of the

studies reporting no significant differences between the two extraction patterns, one did not have mandibular incisor retraction as a part of the treatment plan.⁷⁵ The other based the extraction patterns on pre-treatment characteristics, it included patients with both maxillary first and second premolars extracted, and it used the A-point to pogonion as a reference line, which could be affected by growth and/or treatment.^{71,75}

The effects of 4/4 and 4/5 extractions on molar movements are also controversial. Al-Nimri, who studied Class II division I patients, found significantly more molar mesial movement when the lower second premolars were extracted.⁸³ In contrast, Shearn and Woods, who quantified molar movement by subtracting the change in arch length from the amount of incisor retraction from a mandibular superimposition found no significant difference relating to the extraction pattern.⁷¹ However, the Shearn and Woods samples were not homogenous including both Class I and Class II patients. Wang et al also found no significant difference when measuring molar movements based on the cranial base superimposition.⁸⁴

The major reason for these inconsistent results is the complexity of the study design. Most of the studies comparing 4/4 and 4/5 extraction patterns did not control for crowding, the vertical skeletal pattern, the anteroposterior skeletal pattern, or molar occlusion. Also, the references lines used by the studies for comparing tooth movement are inconsistent and some are affected by growth as well as tooth movement. Moreover, several of the studies were biased because the patients' pre-treatment characteristics dictated the extraction pattern used which might be expected to offset results. Within

and between study variability makes the results confusing and hard to apply to the clinical setting.

The aim of the present study was to evaluate mandibular incisor and molar movements in growing Class II Division I patients who either had 4/4 or 4/5 extraction patterns. Efforts were made to ensure that the two samples were similar prior to treatment, with both groups exhibiting mild to no crowding, a normal range of vertical patterns, and the same anteroposterior skeletal and dental relationship. It is expected the extractions of lower first premolars will result in greater lower incisor retraction and the extraction of lower second premolars will result in more mesial movement of the lower first molar. The purpose of this research is to test these well-accepted concepts of incisor and molar movements associated with these extraction patterns; such evidence will enable orthodontists to provide evidence-based treatment for their patients.

MATERIALS AND METHODS

Sample Description

The sample includes 54 growing extraction cases treated by two private practice orthodontists. The treatment mechanics used included Tweed mechanics, headgears, and class II elastics or safe springs. Arch wires and sometimes headgears were used to derotate the upper first molars. Sliding and frictionless (closing loops) mechanics were used in space closure on a 19x25 stainless steel arch wire. High pull J hook headgears were used to retract maxillary anterior teeth. Class II elastics and safe springs were used as needed.

To be selected the patients had to meet the following inclusion criteria: 1. Class II skeletal relationship (defined by ANB greater than 4°), 2. Class II Division I malocclusion with \geq half-step molar and canine relationships bilaterally, 3. Between the ages of 10 and 17 years, 4. Treatment with extraction of upper first premolars and either lower first or second premolars, 5. Permanent dentition (excluding 2nd and 3rd molars), 6. Successful treatment outcome defined as Class I molar and canine relationships, along with a normal overjet and overbite, 7. Complete records with pre- and post-treatment lateral cephalograms. Patients were excluded if they met the following criteria: 1. Treated with functional appliances, quad helix or RPE before or during fixed appliance therapy, 2. Congenital anomalies, significant facial asymmetries, or congenitally missing teeth. This study was approved by the Texas A&M University College of Dentistry Institutional Review Board (IRB2016-0479).

The sample was divided based on the two extraction patterns: upper and lower first premolars (4/4) or upper first and lower second premolars (4/5). The two groups were matched based on sex, pre-treatment ANB, and pre-treatment MPA. The 4/4 group included 27 patients (15 males, 12 females) treated over 2.8 ± 0.60 years. Their average pre- and post-treatment ages were 12.9 ± 0.98 years and 15.7 ± 0.98 years, respectively. The 4/5 group consisted of 27 patients (10 males, 17 females) treated over 2.6 ± 0.54 years. Their average pretreatment age was 12.3 ± 1.3 ; with an average post-treatment age of 14.9 ± 1.4 .

Cephalometric Methods

Ten skeletal and dental landmarks were identified using standard definitions (Table 1).⁸⁷ All the cephalograms were digitized by one investigator using Dolphin® Imaging Software (Version 11.8, Build 24). Four traditional measurements were used to quantify the anteroposterior (SNA, SNB, ANB) and vertical (S-N/Go-Me) changes of the maxilla and mandible.

Cranial base, maxillary and mandibular superimpositions of the pre- and post-treatment lateral cephalograms were performed for each subject using naturally stable structures.⁸⁸⁻⁹¹ To quantify the horizontal and vertical changes that occurred during treatment, a rectangular coordinate system was used with a horizontal reference line (RL) constructed on the T1 cephalometric tracing.⁹² The RL was registered on T1 Sella and oriented 7 degrees below the SN to approximate natural head position (Figure 1).⁹² The horizontal and vertical changes of the teeth were measured parallel and measured perpendicular to RL, respectively (Figure 2).⁹² Changes in molar position were measured at the mesial buccal cusp tip and the mesial contact point. The horizontal and vertical changes of the incisor movements were measured at the cusp tip. Anterior and superior changes were recorded as positive, whereas posterior and inferior measurements were recorded as negative.

TSALD Calculation

TSALD (tooth size arch length discrepancy) was determined by subtracting the space required (size of maxillary and mandibular teeth) from the space available (arch perimeter). The “brass wire” method was used to measure the perimeter of the dentition

in the Ortho-Insight Motion View Software.^{93,94} All pre-treatment casts were scanned using Ortho Insight® 3D scanner (by Motion View Software, LLC, Version 7.0, Copyright 2016) and imported into Dolphin® & Ortho Insight® 3D software. The maxillary and mandibular teeth were segmented and the mesio-distal diameter of the teeth were measured from the distal to mesial anatomical contact points.⁹⁵ Arch perimeters of both arches were measured by placing a curve over the arch, extending from the distal contact point of the right first molar to the distal contact point of the left first molar.^{93,94} The curve was centered over the contact points of the posterior dentition and where the incisors would be upright over basal bone.^{93,94} The Ortho Insight® 3D Motion View software calculated TSALD using the sum of the tooth diameters and arch perimeter, with a negative TSALD indicating crowding and a positive TSALD indicating spacing.

Statistical Method

The skewness and kurtosis statistics showed that the distributions of the measurements were all normal. Means and standard deviations were used to describe the two groups. Independent sample t-test were used to evaluate between-group differences. Paired t-tests were used to evaluate within group differences. Analysis of Covariance was used to evaluate the effect of the L1 anteroposterior position and angulation pre-treatment differences on tooth movement. IBM SPSS Statistic (Version 23, Armonk, NY) was used to perform the statistical analysis. The significant level was set to 0.05.

RESULTS

T1, T2, and Treatment Changes Characteristics

The majority of the 4/4 and 4/5 samples came from one private practice orthodontists, with the other private clinician providing 6 patients of the 4/4 group and 3 patients of the 4/5 group. There were no statistically significant pre-treatment (T1) between-group differences in the SNA, SNB, ANB, MPA, UTSALD, and LTSALD (Table 2). Both treatment groups exhibited Class II maxillomandibular relationships ($ANB \approx 5.52^\circ$) and a normodivergent ($MPA \approx 34.5^\circ$) skeletal patterns. There were significant differences in pre-treatment IMPA, L1:NB, and L1:APo (Table 2).

The treatment changes of the SNA, SNB and ANB angles as well as the MPA angles also showed no statistically significant differences between the 4/4 and 4/5 groups (Table 3). The 4/4 group's MPA increased slightly ($\approx 0.12^\circ$) and the 4/5 group's MPA decreased slightly ($\approx -0.35^\circ$), but neither the within- or between-group differences were statistically significant. The SNA and ANB angles showed statistically significant within-group changes for both groups. The SNB angle of the 4/5 group also showed a statistically significant within-group change. Both groups showed improvements in the ANB angle, due mostly to decreases in the SNA and slight increases in the SNB. There were no statistically significant post-treatment (T2) between-group differences for SNA, SNB, ANB, or MPA (Table 4).

Maxillary and Mandibular Jaw Displacements

There were no statistically significant between-group differences in the amount of horizontal and vertical maxillary and mandibular jaw displacements (Table 5 & 6,

Figure 3 & 4). The amount of horizontal displacement between the two groups differed approximately 0.36 mm in maxilla and 0.04 mm in the mandible. The amount of vertical displacement between the two groups differed approximately 0.19 mm in the maxilla and about 0.47 mm in the mandible.

Maxillary and Mandibular Molar Horizontal and Vertical Tooth Movements

The horizontal and vertical tooth movements of the maxillary and mandibular molars were statistically significant within each group. The U6s moved mesially approximately 1.9-2.2 mm. There was a tendency for the 4/5 group to show slightly greater amounts of mesial movement than the 4/4 group, but the group differences were not statistically significant (Table 5, Figure 3). The L6s moved mesially approximately 4.2-5.1 mm. There was a significant between-group differences in the migration of the L6 occlusal contact point. The L6 migrated approximately 0.74 mm more in the 4/5 group than in the 4/4 group (Table 5, Figure 3). There was a tendency for slightly greater mesial movement of the mandibular molar in the 4/5 group, but only the L6 occlusal contact point was significant.

While there was slightly greater eruption (0.2-0.6 mm) of the U6 in the 4/5 group, the differences were not statistically significant (Table 6, Figure 4). Eruption of the L6 was also not statistically different between the two groups. There was a tendency slightly greater eruption (0.4-0.5 mm) in the 4/4 group, but the differences were not statistically significant (Table 6, Figure 4).

Maxillary and Mandibular Incisor Horizontal and Vertical Tooth Movements

The amount of retraction of the maxillary and mandibular incisors showed statistically significant within-group differences. The maxillary incisors were retracted 1.42 mm more in the 4/4 group, but the difference was not significant (Table 7, Figure 3). The lower incisors were retracted significantly more (1.57 mm) in the 4/4 group. Analysis of Covariance controlling for IMPA and L1:APo, resulted in statically significant ($p=0.017$, $p=0.042$) between-group differences in the amount of lower incisor retraction. Analysis of Covariance controlling for L1:NB resulted in no statistically significant ($p=0.148$) between-group differences in the amount of lower incisor retraction.

There were no significant within-group differences in the U1 eruption in both the 4/4 and 4/5 group and the L1 eruption in the 4/5 group. There were no significant between-group differences in the amount of eruption in the maxillary and mandibular incisors (Table 8, Figure 4).

DISCUSSION

To minimize selection bias, it is important to ensure that the cohorts being compared are as similar as possible prior to treatment. This is particularly important when the cohorts have not been randomly allocated. The two groups in the present study did not exhibit any pre-treatment differences in the ANB, SNA, and SNB angles, or in the MPA and crowding. However, the two groups did significantly differ in the pre-treatment lower incisor angulation and AP position (IMPA, L1:NB, L1:APo). Previous

studies evaluating these extraction patterns have had trouble controlling for pre-treatment differences. Previous studies have based their extraction pattern on overjet, molar relationship, facial axis, ANB angle, overbite, crowding, and posterior face height ratio.^{71,72,75,83,84} The goal is to have treatment be the only factor that differs between the two groups. If the groups differ initially, or if an extraction sequence is based on the patients' pre-treatment characteristics, the results could be biased.

There were significant between-group differences in the pre-treatment IMPA, L1:NB, and L1:Apo. The 4/4 groups showed significantly greater amounts of protrusion (2.0 mm) and proclination (4.2°) in the lower incisors compared to the 4/5 group. The lower incisors in the 4/5 group appear to be in a relatively normal anteroposterior position (L1:NB) and angulation (IMPA) for age specific norms and slightly retrusive compared to the age specific norms for L1-APo.⁸⁷

Based on the pre-treatment differences in lower incisor position, it can be speculated that the two private practice orthodontists determined the extraction pattern based on the lower incisor anteroposterior position and angulation. Historically, the teeth most commonly extracted for orthodontic treatment were the four first premolars.⁹⁶ Nance was one of the first clinicians to suggest the extraction of second premolars because it would result in less incisor retraction and therefore less lip retraction compared to first premolar extractions.⁶¹ Second premolar extractions have been suggested as an alternative to first premolar extractions in patients with mild crowding, acceptable incisor position, and relatively acceptable profile.^{62,97,98} In this study, the two private practice orthodontist recommended lower second premolar extraction in

patients with mild crowding and with a lower incisor in a relatively good anteroposterior position and angulation.

Extracting lower first premolars results in greater lower incisor retraction than extracting lower second premolars. The results from the present study showed that the 4/4 group had significantly more retraction of the lower incisors than the 4/5 group (3.4 mm vs 1.8 mm). The initial differences in lower incisor anteroposterior position and angulation (IMPA, L1:NB, L1:APo) were statistically significant. In order to control for these pre-treatment differences, the Analysis of Covariance was used to determine if the amount of retraction could be explained by these pre-treatment differences. When controlling for pre-treatment differences in IMPA and L1:APo, the results still showed statistically significant between-group differences in the amount of mandibular incisor retraction; however, there was no significant between-group differences in incisor retraction when the L1:NB pre-treatment difference was controlled for. These results indicate that the pre-treatment difference in L1:NB partially explains the difference in the amount of retraction between the two extraction groups. Conversely, the pre-treatment IMPA and the pre-treatment L1:APo position did not affect the amount of retraction between the two groups; with more incisor retraction resulting from the extraction pattern and not from the lower incisor position relative to IMPA or L1:APo.

While most of the literature shows a tendency for greater lower incisor retraction with lower first premolars than lower second premolar extractions, with differences ranging from 0.8 mm to 2.4 mm,^{71,72,75,84} only one study has reported statistically significant differences.⁷² The lack of significant between-group differences could be due

to intentionally not trying to retract incisors,⁷⁵ selection bias,^{71,72} lack of anchorage control,^{71,72,75,84} or small sample sizes.⁷¹ The one study showing significant differences between the 4/4 and 4/5 extraction patterns reported approximately 0.3 to 0.7 mm more incisor retraction when mandibular first premolars were extracted.⁷² This is approximately 0.6 mm to 1.3 mm less retraction than observed in the present study for the 4/5 and 4/4 groups, respectively. One possible reason for more incisor retraction in the current study was crowding. The samples evaluated by Steyn et al had more crowding, which results in less space for retraction. Steyn et al study also did not use extra-oral anchorage during space closure, and Class II mechanics were used to maintain Class I molar relationship which advance and procline the lower incisors, negating the amount of retraction.^{99,100} The references lines used to measure tooth movement were also different than the references lines used in the present study, making it hard to compare the results.

A possible explanation for greater amounts of incisor retraction with the extraction of the lower first premolars is root surface area. In extraction cases with reciprocal space closure, the anterior teeth are pitted against the posterior teeth. In 1969, Williams proposed that the amount of anterior retraction was directly correlated to the root surface areas of the anterior and posterior teeth.¹⁰¹ The greater the root surface area, the greater the resistance to tooth movements.^{86,101,102} Since the posterior root surface areas decrease with the extraction of second premolars, the relative amount of anterior root surface area increases, which might be expected to influence the amounts of incisor retraction that occur.^{86,101} There is less incisor retraction with the extraction of lower

second premolar because posterior anchorage is greater with the extraction of lower first premolars.

The position of the extraction site provides another possible explanation for the greater amounts of incisor retraction observed with the extraction of lower first premolars. The teeth closest to the extraction space move more than teeth further away. When only first premolars were extracted (i.e. no orthodontic appliances placed) in the permanent dentition, the extraction spaces closed mainly due to distal drifting of the mandibular canines and incisors.^{103,104} This also occurred when the extractions were performed in the mixed dentition.^{105,106} This mechanism might also be expected to apply in adolescent patients when appliances have been placed. When lower second premolars are extracted, any distal movement of the anterior teeth would be limited by the first premolars (i.e. less potential for tipping and drifting into the extraction spaces). With the extraction of the lower first premolars, nothing prevents the anterior teeth from retracting, facilitating retraction of the anterior teeth and making distal drift/tipping more likely.

The extraction of either the lower first or second premolar has little or no effects on the vertical dimension. In other words, there does not appear to be a wedge effect with either of the extraction patterns. The present study showed no significant between-group difference in the changes of the MPA during treatment. Neither group showed changes of the MPA; the two extraction groups also showed similar amounts of vertical tooth movement (vertical displacement, and eruption). The notion of the wedge effect was first introduced in the 1960-70's, when extractions were recommended for high

angle patients to “close down the bite” and upright incisors.^{78,107,108} This notion was later expanded to incorporate different extraction patterns. The extraction of the mandibular second premolars was thought to allow the mandibular molars to move mesially more than the extraction of first premolars. This idea was based on the assumption that, while the mandible rotates around a center located near the condyle, greater mesial movements of the molars might be expected to produce greater decreases in the facial vertical dimension than lesser mesial movements.

However, decreases in the vertical dimensions cannot be supported. The present study, as well as three previous studies comparing the 4/4 and 4/5 extraction patterns, have all shown no between-group differences in vertical facial dimensions.^{72,83,84} Wang et al reported similar amounts of vertical change (lower anterior face height, posterior face height, posterior face height to anterior face height ratio) in Class I normodivergent patients during orthodontic with either 4/4 and 4/5 extractions.⁸⁴ They showed significant and unexpected between-group differences in the MPA (increases in the 4/5 group and a decreases in the 4/4 group).⁸⁴ Another study evaluating Class I patients showed that facial divergence of both extraction patterns increased slightly (0.8%).⁷² The final study of Class II Division 1 normodivergent patients reported no significant between-group differences in mandibular divergence between 4/4 and 4/5 extraction patterns.⁸³

Greater and lesser changes in vertical facial dimension can be explained by increased or decreased amounts of molar eruption. For mandibular rotation to occur, the maxillary and mandibular molars either need to be intruded, or their vertical eruption

during growth needs to be prevented. During growth, teeth continue to erupt and migrate after they come into occlusal contact. The current study showed that the upper molars erupted approximately 2.2-2.3 mm during the 2.7 years of treatment period, as expected during normal growth.¹⁰⁹ However, the lower molars erupted approximately 2.4-2.5 mm over the same period, which is slightly more than expected in untreated subjects. The lower molar extrusion observed were probably related to the Class II mechanics (elastics or safe springs) that were used to correct the malocclusion. The increased amount of eruption that occurred could have prevented decreases expected in the vertical dimension.

Traditional orthodontic treatments (especially Class II mechanics) cause the molars to extrude with increases of the MPA.¹¹⁰⁻¹¹⁴ Regardless of extraction or non-extraction, the mandible is typically displaced downward and rotates forward with growth, with concomitant increases in face height.¹¹⁵⁻¹¹⁷ It usually rotates forward because it is displaced down more in the back than the front.¹¹⁵ Both the extrusion of molars and growth will cause increases in vertical dimensions and potentially increases the MPA. In order to produce mandibular forward rotation it is important to control the vertical positions of the teeth.¹¹⁸ Regardless how much the lower molars move mesially, the vertical dimension cannot be decreased unless the vertical eruption is controlled. This is expected because the mandible does not rotate around the condyle during growth. It typically rotates around a point located in the anterior dentition, ideally around the incisors.¹¹⁹

There is greater mesial movement of the mandibular molar and less incisor retraction with lower second premolar extractions than with lower first premolar extractions. The results from the present study showed approximately 0.7 to 0.8 mm more mesial movement of the lower molar when the second premolar was extracted. Once again, the existing literature is controversial concerning the effects of different extraction patterns on lower molar mesial movements.^{71,83,84} The amounts of mesial movement previously reported ranged from 2.0-4.5 mm.^{71,83,84} Al-Nimri reported 1.8 mm more mesial movement among growing Class II Division I normodivergent patients who had lower second than first premolars extracted, which was significantly different.⁸³ No significant between-group differences have also been reported, with both groups showing approximately 4-4.5 mm of lower molar mesial movement.^{71,84} These amounts of mesial movement previously reported were similar to those observed in the present study, with the exception of the Al-Nimiri 4/4, who showed substantially less. This difference could have been due to the amount of initial crowding. The difference in mesial molar movement between the two extraction groups were reported to be insignificant in the two studies, which was most likely due to small sample size,⁷¹ selection bias⁷¹ or lack of extra-oral anchorage.^{71,84} Moreover, some of the studies did not separate molar migration from jaw displacement making it more difficult to identify differences in molar movement.^{71,84}

The two possible reasons given for greater amounts of lower incisor retraction with lower first premolar extractions could also explain why there is more mesial movement of the lower first molar and less incisor retraction with the extraction of

second premolars. Second premolar extractions decrease the amount of root surface area in the posterior segment and increases the relative root surface area of the anterior segment. The anchorage or amount of resistance in the anterior segment would be increased, making it more likely for greater lower molar mesial migration. Also, the second premolars might be expected to impede the first molars when first premolars are extracted, resulting in less mesial migration of the first molars. This explains why, during second premolar serial extractions, a significant portion of space is closed by mesial drift of the lower molars.¹²⁰ Greater mesial migration of the mandibular first molars in the second premolar extraction might also be due to the difference in the mesio-distal widths of the mandibular first and second premolars. The second premolar is approximately 0.3 mm larger than the first premolar.¹²¹

Clinical Considerations

It is important to emphasize that the patients in the present study had moderate to severe Class II malocclusions (bilateral ½ step or greater Class II molar and canine) prior to treatment and all ended treatment with a Class I molar and canine relationships. Since both groups were similar in both skeletal and dental relationships at the start of treatment, the lower molar had migrated mesially approximately the same distance in both groups in order to achieve a Class I relationships. This helps to explain why there were not greater differences in molar migration between the two extraction groups. It is reasonable to expect that if the extraction space had been closed reciprocally, without correcting the malocclusion, the difference in molar movement between lower second and first premolar extractions would have been greater than the 0.7-0.8 mm difference

found in the present study. In addition, if the anchorage in the anterior segment would have been enhanced (e.g. buccal mini-screw implants), then the amount of lower mesial migration would also have been greater.

There are several potential advantages associated with extraction of lower second premolars. First, greater mesial migration of the lower molars could shorten treatment time. In the present study, the lower second premolar extraction group's treatment time was only 0.2 years shorter than the lower first premolar extraction group's treatment time. However, this two-month difference is important clinically because longer duration of orthodontic treatment has been associated to increased risk of decalcification, dental caries, root resorption, and gingival inflammation.¹²²⁻¹²⁶ In addition, patients prefer shorter treatment time. Depending on the extent of the Class II malocclusion and the anchorage used in the maxillary arch, less use of Class II elastics usage might be expected with the extraction of lower second than lower first premolars. Due to the extraction site location and root surface area, additional force (ex: Class II elastics) would be required to protract the lower molars that same amount in first premolar than second premolar extraction cases. This is important because the use of Class II elastics should be limited in most cases, due to their negative side effects (extrusion of molars, proclining and advancing lower incisors).^{99,100,110-114}

In the present study, the upper first molars also played an important role in the Class II correction. The upper first permanent molars are rotated mesially in approximately 80% of Class II patients.^{127,128} According to Andrews' six keys to normal Class I occlusion, they should not be rotated.¹²⁹ Rotated first molar cause occlusal

problems and they occupy space.¹²⁹ Correct maxillary molar rotations improves intermolar anteroposterior relationships^{127,130} and increases arch perimeter.^{128,130,131} The correction of a molar rotation provides 1-2 mm of space, which helps the correction of a Class II molar relationships.^{128,130,131} A full step Class II represent approximately 6 mm of discrepancy, while a ½ step represents approximately 3 mm of discrepancy. Upper molar rotation can provide 1-2mm of correction if the molar is held once it is derotated.

Finally, lower incisor position and soft tissue profile must always be considered when correcting Class II malocclusions. The extractions in the present study were not based on crowding; most of the patients had minor crowding. Instead, they were performed so that the lower incisors would not be proclined when correcting the Class II malocclusion and leveling the curve of Spee. Second premolar extractions might need to be considered after evaluating the current incisor position and soft tissue profile in Class II Division I patients. Extracting lower second premolars allows the orthodontist to maintain the incisor in the relatively same anteroposterior position and correct the malocclusion. Extracting lower first premolars produces greater incisor retraction and could result in a greater profile change.

CHAPTER III

CONCLUSIONS

This study evaluated the horizontal and vertical incisor and molar movements in Class II Division I normodivergent patients receiving 4/4 or 4/5 extractions. The following conclusions can be drawn:

1. The lower incisors are retracted significantly more after mandibular first premolar than mandibular second premolar extractions.
2. The mandibular first molars migrate mesially significantly more after mandibular second premolar than mandibular first premolar extractions.
3. There is no significant difference in the change in MPA for either group and there were no significant between-group differences in the change in MPA or in the vertical eruption of the maxillary and mandibular molars when comparing the 4/4 and 4/5 extraction groups.

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APPENDIX A

FIGURES

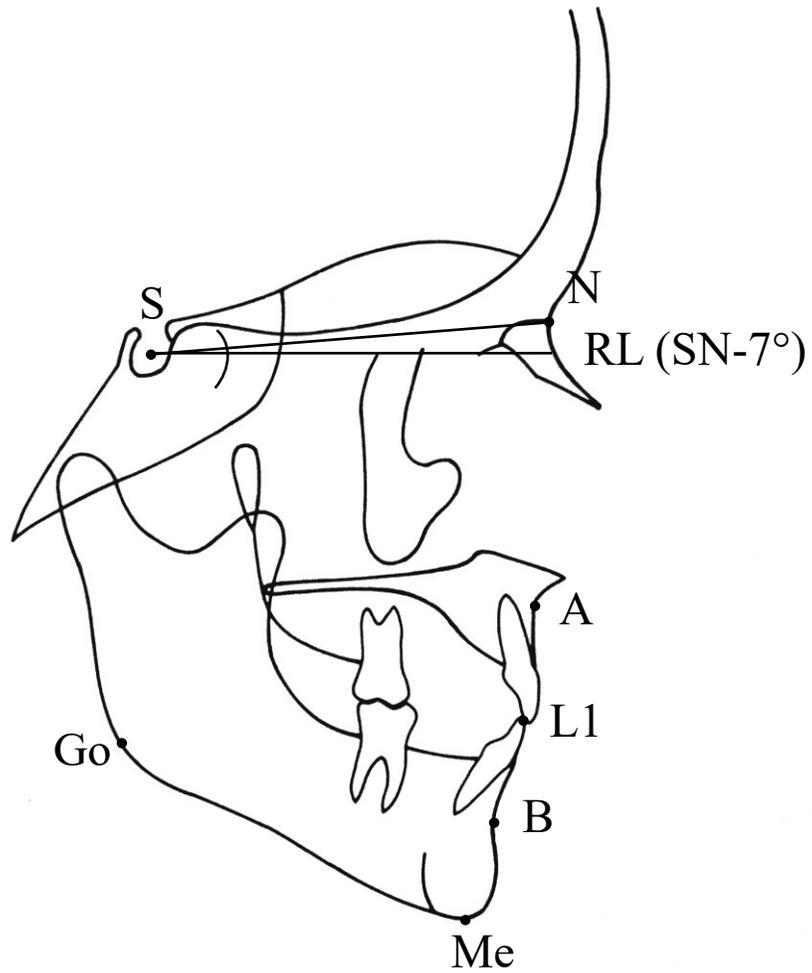


Figure 1. Horizontal reference line oriented on the T1 SN-7°, registering on T1 sella (Reprinted & slightly adapted from ⁹²)

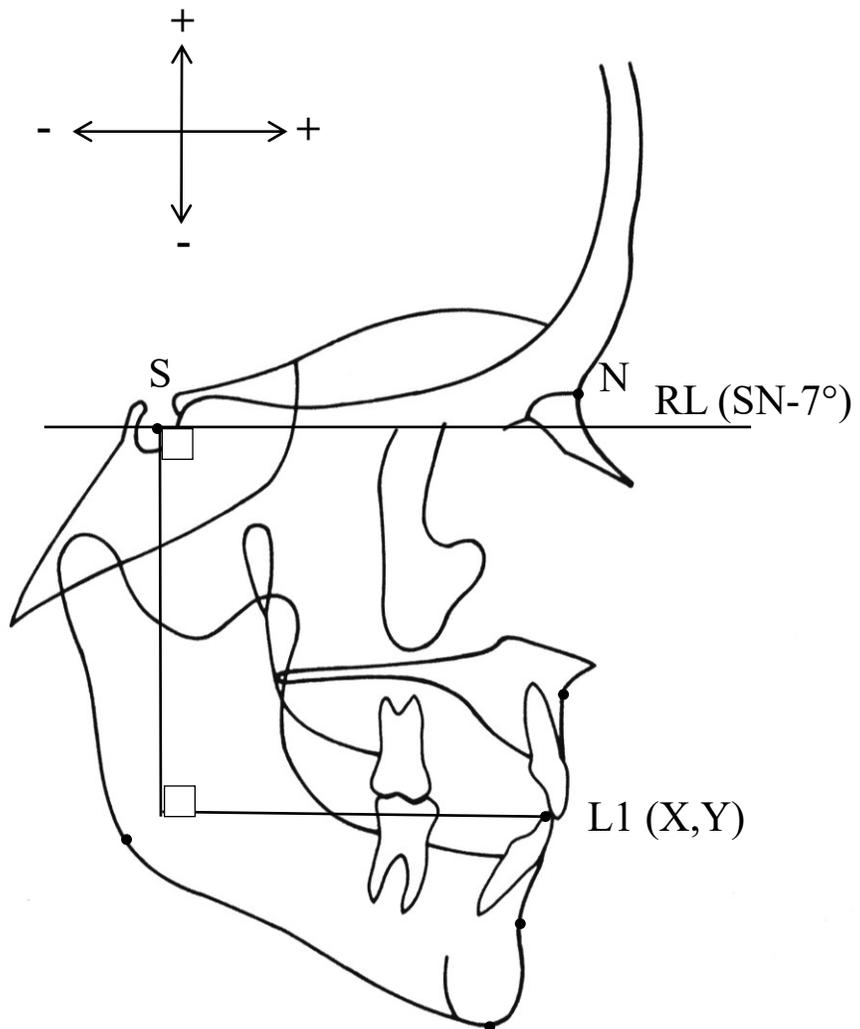


Figure 2. Cephalometric landmarks measured parallel and perpendicular to the reference line oriented on T1 SN-7° (Reprinted & slightly adapted from ⁹²)

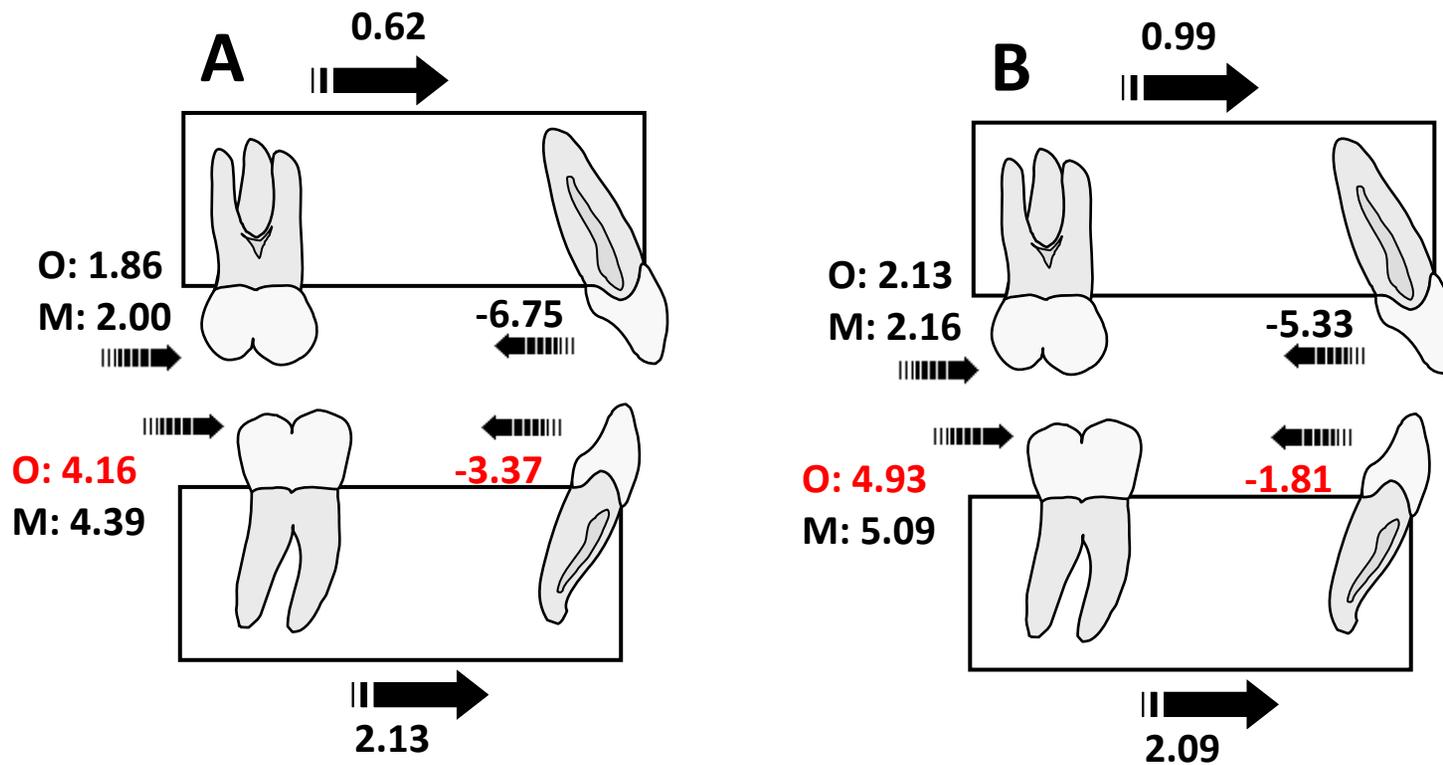


Figure 3. Horizontal jaw and tooth movements comparing 4/4 and 4/5 extraction groups (red indicates significance)
 A: 4/4 grp B: 4/5 grp

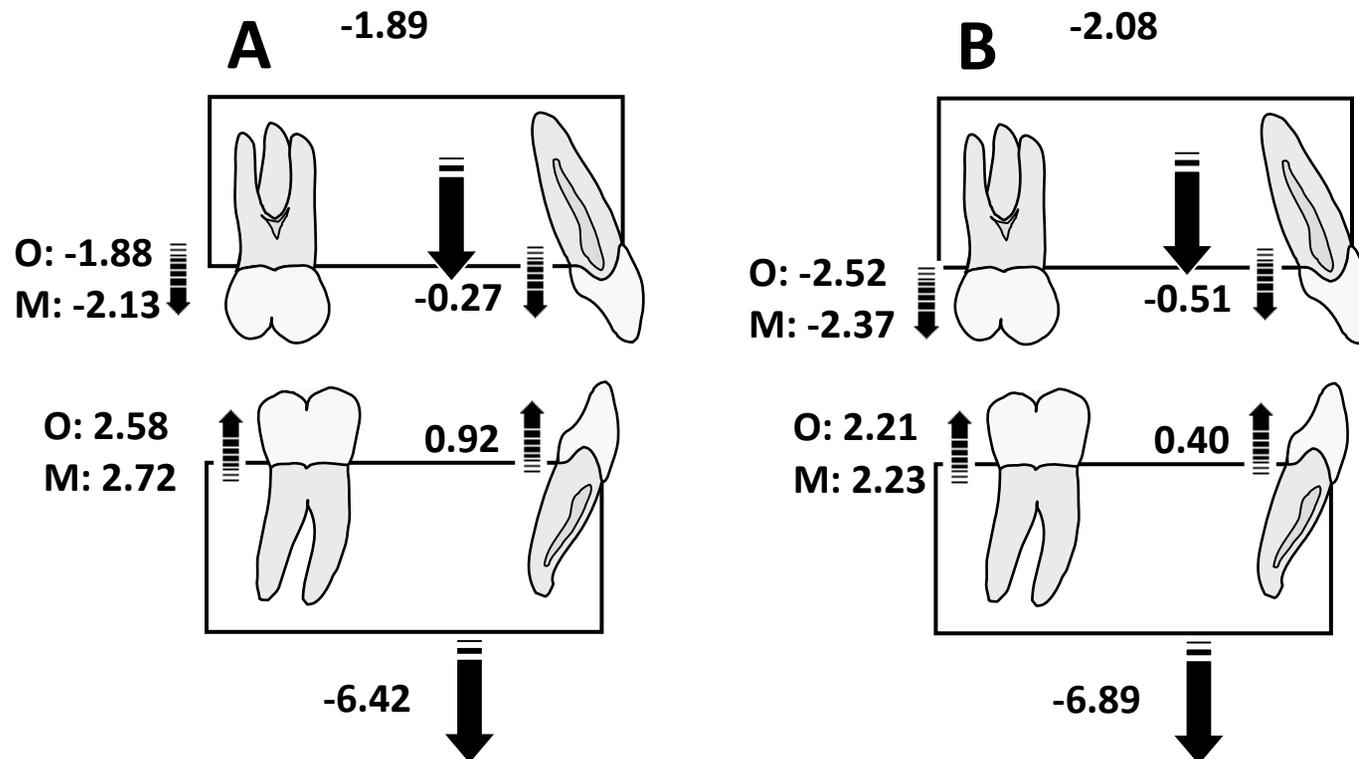


Figure 4. Vertical jaw and tooth movements comparing 4/4 and 4/5 extraction groups
A: 4/4 grp B: 4/5 grp

APPENDIX B

TABLES

Table 1. Cephalometric Landmark Abbreviation and Definitions

Abbreviation	Definition
S	Sella: the center of the pituitary fossa
N	Nasion: the most anterior point on the frontonasal suture
Me	Menton: the most inferior point on the symphyseal outline of the mandible
Go	Gonion: the midpoint of the angle of the mandible
A	A point: the most posterior midline point in the concavity between ANS and prosthion
B	B point: the most posterior midline point in the concavity between infradentale and pogonion
U1 Incisal Edge	The incisal cusp tip of the most facial upper incisor
U6 Occlusal	The mesial buccal cusp tip of the maxillary first molar
U6 Mesial	The mesial contact point of the maxillary first molar
L1 Incisal Edge	The incisal cusp tip of the most facial lower incisor
L6 Occlusal	The mesial buccal cusp tip of the mandibular first molar
L6 Mesial	The mesial contact point of the mandibular first molar

Table 2. Pre-Treatment (Pre-Tx) Characteristics of Extractions Groups: Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5)

T1 (Pre-Tx)	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>		
<i>Measurements</i>						
SNA	81.19	3.45	81.34	3.23	-0.15	0.871
SNB	75.49	2.79	75.90	2.98	-0.41	0.603
ANB	5.69	1.49	5.43	1.40	0.26	0.507
MPA	34.77	2.94	34.20	3.58	0.57	0.522
IMPA	97.96	4.60	93.76	6.34	4.20	0.007**
L1:NB (mm)	6.63	1.40	4.50	1.63	2.13	<0.001**
L1:APo	2.07	1.49	0.07	1.79	2.00	<0.001**
UTSALD	-1.51	3.09	0.01	4.01	-1.51	0.126
LTSALD	-1.30	3.01	-0.90	1.90	-0.39	0.569

**Significance if p<.05

Table 3. Pre- to Post-Treatment Skeletal Changes in Extractions Groups: Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5)

T1-T2 Changes <i>Measurements</i>	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>		
SNA	-2.43	1.25	-2.16	0.94	-0.27	0.374
SNB	0.23	1.34	0.61	1.19	-0.38	0.273
ANB	-2.69	0.99	-2.74	0.99	0.56	0.837
MPA	0.12	1.19	-0.35	1.04	0.47	0.132

Bold= statistically significant (p<.05) within-group changes

Table 4. Post-Treatment (Post-Tx) Characteristics of Extractions Groups: Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5)

T2 (Post-Tx) <i>Measurements</i>	4/4 (n=27)		4/4 (n=27)		Mean Difference	Significance (p-value)
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>		
SNA	78.76	3.25	79.17	3.22	-0.42	0.637
SNB	75.71	2.58	76.51	3.04	-0.79	0.307
ANB	3.01	1.14	2.69	1.27	0.32	0.338
MPA	34.89	3.24	33.85	3.77	1.04	0.282

**Significance if p<.05

Table 5. Horizontal Jaw Displacement and Molar Mesial Movement Changes in Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5) Extraction Groups

Point Measured	Movement Type	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
		<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>		
U6 _{occl}	Migration	1.86	1.34	2.13	0.98	-0.27	0.395
U6 _{mes}	Migration	2.00	1.29	2.16	0.90	-0.16	0.588
Maxilla	Displacement	0.62	0.84	0.99	0.73	-0.36	0.096
L6 _{occl}	Migration	4.16	1.19	4.93	1.50	-0.77	0.041**
L6 _{mes}	Migration	4.39	1.31	5.09	1.30	-0.71	0.052
Mandible	Displacement	2.13	1.78	2.09	1.45	0.04	0.934

**Significance if p<.05

Table 6. Vertical Jaw Displacement and Molar Eruption Changes in Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5) Extraction Groups

Point Measured	Movement Type	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>		
U6 _{occl}	Eruption	-1.88	1.25	-2.52	1.51	0.64	0.095
U6 _{mes}	Eruption	-2.13	1.29	-2.37	1.60	0.23	0.557
Maxilla	Displacement	-1.89	1.33	-2.08	1.29	0.19	0.598
L6 _{occl}	Eruption	2.58	1.40	2.21	1.59	0.36	0.379
L6 _{mes}	Eruption	2.72	1.37	2.23	1.61	0.49	0.236
Mandible	Displacement	-6.42	3.04	-6.89	3.27	0.47	0.586

**Significance if p<.05

Table 7. Horizontal Incisor Movement Changes in Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5) Extraction

Point Measured	Movement Type	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>		
U1	Retraction	-6.75	2.64	-5.33	2.73	-1.42	0.057
L1	Retraction	-3.37	1.88	-1.81	1.17	-1.57	0.001**

**Significance if p<.05

Table 8. Vertical Incisor Movement Changes in Maxillary and Mandibular 1st Premolars (4/4) and Maxillary First and Mandibular Second Premolars (4/5) Extraction Groups

Point Measured	Movement Type	4/4 (n=27)		4/5 (n=27)		Mean Difference	Significance (p-value)
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>		
U1	Eruption	-0.27	2.37	-0.51	2.08	0.24	0.696
L1	Eruption	0.92	2.00	0.40	1.65	0.52	0.306

Bold= no statistically significant (p<.05) within-group changes