Effects of Unilateral Premolar Extraction Treatment on the Dental Arch Form of Class II Subdivisions

BY

GINU DEVI DAHIYA
B.Sc., University of Toronto, 2009
D.M.D., Case Western Reserve University, 2013

THESIS
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Defense Committee:

Carlotta A. Evans, Chair and Advisor
Budi Kusnoto
Ales Obrez, Restorative Dentistry
Maria Grace Costa Viana

This thesis is dedicated to my sister, Shiksha Dahiya, whose sacrifice and efforts allowed me to pursue my orthodontic career. I would also like to dedicate this dissertation to my parents, Promila and Rajvir Dahiya, as their support and love made me who I am today. Lastly I would like to dedicate this thesis to my partner, Lutful Sanju, who has helped me stay sane through this process and whose assistance helped me to pursue my dreams.

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I would also like to acknowledge Pritesh Parmar for the many hours he spent in helping to write the code for the MATLAB™ program, without which this research project would not have been possible. I am also grateful to Ahmed Masoud for his time spent in de-identifying subjects and for serving as the honest broker.

G.D.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
FA	Facial Axis
JPEG	Joint Photographic Experts Group standard compressed image
MEAW	Multiloop Edgewise Archwires
PA	Postero-Anterior Cephalometric radiograph
SD	Standard Deviation
SMV	Submental Vertex radiograph
STL	Stereolithograph
TAD	Temporary Anchorage Device

SUMMARY

Understanding and treating Class II subdivision malocclusions is challenging and requires a precise and thorough analysis of the source of the asymmetry. Asymmetric extractions have been proposed as potential treatment options to correct occlusions with pre-existing imbalance, suggesting that most side effects associated with asymmetrical mechanics can be avoided.

The objective of this study was to evaluate maxillary post-treatment arch shapes and midlines for any asymmetry in Class II subdivision malocclusions treated with unilateral and bilateral premolar extractions. It was hypothesized that the distances of all corresponding points between right and left sides of the dental arch are approximately the same in the transverse and sagittal dimensions for each experimental group. It was also hypothesized that the effect of unilateral premolar extraction treatment on dental arch form symmetry and maxillary midline deviation from the palatal raphe is not significantly different in comparison to bilateral premolar extractions.

Paired t-tests were performed to test the mean difference between corresponding values on the right and left sides of the arch within each experimental group. Independent student t-tests were performed to test the mean difference between testing and control groups of the variables involved in the study.

Results found the width of analogous points between right and left sides of the dental arch in the transverse and sagittal dimensions to be approximately the same for those patients treated with bilateral premolar extractions, but not those treated with unilateral premolar

extractions. The latter group showed statistically significant mean differences in the anterior, anterior-middle and middle segments of the arch in the transverse dimension, and all segments of the arch aside from the posterior segment in the sagittal dimension ($P<0.05$). The general pattern was a narrower and more posteriorly displaced arch form on the extraction side. Between the two groups, the anterior and anterior-middle segments showed statistically significant mean differences in the transverse dimension, and the middle and middle-posterior segments in the sagittal dimension ($P<0.05$). A statistically significant difference in midline deviation relative to the mid-sagittal plane was observed between the two groups ($P<0.05$), with the unilateral extraction group consistently displaying deviation of the maxillary midline towards the extraction side of the arch.

1. INTRODUCTION

1.1 Background

There is little consistency in the use of the term subdivision in the orthodontic community as well as a lack of widespread agreement on the definition of Class II subdivisions. For over a hundred years the basis of orthodontic terminology has relied on Edward H. Angle's definitions of Class I, II and III malocclusions, as it is customary for orthodontists to abide by Angle's instruction when classifying malocclusions (Artun et al., 2013). Although Angle clearly states that a subdivision is the existence of a unilateral malocclusion, with one normal and one abnormal side, he does not specify if the subdivision occurs in the normal or the abnormal side, causing orthodontists and educators to interpret his teachings differently (Artun et al., 2013). As reported by Siegel (2002), surveys sent to 57 orthodontic departments in the US revealed less than 65% agreement on whether subdivision refers to the normal side, or the affected side. This difference of opinion in the characterization of subdivisions promotes misunderstanding of Class II subdivision cases and encourages uncertainty and confusion.

In terms of the frequency of Class II subdivision cases, studies have found that the prevalence of asymmetric molar occlusions in untreated adolescents in the United States is less than 30%. The most common asymmetry trait among orthodontic patients, which occurred in 62% of patients, was the mandibular midline deviation from the facial midline, followed, in descending order of frequency, by absence of dental midline coincidence at 46%, maxillary midline deviation from the facial midline at 39%, molar classification asymmetry at 22%, maxillary occlusal asymmetry at 20%, mandibular occlusal asymmetry at 18%, facial asymmetry at 6%, chin deviation at 4%, and nose deviation at 3% (Sheats et al., 1998). The fact that Class II subdivisions account for up to 50% of all CII malocclusions, and are one of the more common dental asymmetries amongst orthodontic patients, means that the location and degree of asymmetry are of interest (Rose et al., 1994).

Class II subdivision orthodontic cases are more complex than symmetrical cases, and understanding the etiology and source of the asymmetry in these cases is challenging. Due to this, Class II subdivision cases have long posed a treatment challenge for orthodontists. The initial step to correctly diagnose any type of asymmetry is to manipulate the patient into central relation and verify the true position of the jaw, thereby omitting any possibility of a functional shift (Minich et al., 2013). In order to achieve favorable outcomes in Class II subdivision cases, it is imperative that the clinician make the appropriate diagnosis by accurately identifying the location of the asymmetry – whether it is in the maxilla, the mandible or both. Further investigation must also be done in order to identify whether a skeletal component is involved, or if the asymmetry is solely dento-alveolar in nature (Burstone, 1998; Nanda and Margolis, 1996). Skeletally, the entire maxilla may be positioned further forward on the Class II side, or the mandible retruded, or a combination of the two. In other situations, however, the maxillary and mandibular skeletal components may be well-positioned in relation to the face and cranium, and the cause of the Class II relation is the denture malposition upon the skeletal bases. There may also exist a combination of disharmony in skeletal relations and the denture to skeletal relations within the same patient (Wertz, 1975). A comprehensive and precise analysis of these subjects in three dimensions would be ideal for successful diagnosis and treatment planning (Kusnoto et al., 2002).

A number of studies have attempted to describe the origin and etiological factors of unilateral malocclusions. Evidence shows that the distal positioning of the mandibular first molar on the Class II side, categorized as a type 1 malocclusion, is the primary element promoting a Class II subdivision (Turpin, 2005). The type II category is characterized by the mesial positioning of the maxillary first molar, which is a secondary contributor (Janson et al., 2007). It has been reported that mandibular midline deviations occur nearly twice as often as maxillary deviations and a deficient mandible is the primary contributing cause responsible for a Class II subdivision malocclusion, due to either reduced ramus height or reduced mandibular length on the Class II side (Cassidy et al., 2014). Despite where the asymmetry lies, the resulting asymmetric occlusal pattern makes for a puzzling brain-teaser that requires careful analysis to solve.

The need to re-establish symmetry in one or both arches makes the treatment of these malocclusions inherently more difficult. Asymmetry from a skeletal component should ideally be corrected with surgery, but it is often the case that this option is refused by the patient, and the orthodontist is compelled to employ other asymmetric options for instance Class II elastics, extra-oral traction, orthodontic distalizers, TADs, fixed functional appliances, or extractions. The extent to which comprehensive orthodontic treatment can correct such asymmetry without surgical intervention is not well documented.

The difficult nature of these malocclusions may be the reason why few studies related to the treatment and outcomes of these cases exist in the literature (Kusnoto et al., 2002). They report on treatment strategies that include evaluation of symmetric versus asymmetric extraction patterns in Class II subdivision cases (Janson, Dainesi, et al., 2003), non-extraction treatment using tip-back mechanics (Shroff et al., 1997), and treatment outcomes using the Herbst appliance (Bock et al., 2013) and asymmetric headgear systems (Brosh et al., 2005). The purpose of this study is to contribute insightful details and conclusions on the outcomes of different treatment strategies implemented in the treatment of these cases, specifically unilateral and bilateral premolar extractions.

1.2 Objective

To determine post-treatment effects of unilateral and bilateral premolar extraction treatment on the dental arch form of Class II subdivision malocclusions.

To determine dental midline deviation relative to the mid-palatal raphe in Class II subdivisions treated with unilateral and bilateral premolar extractions

1.3 Null Hypothesis

H (1) – There are no statistically significant mean differences in the transverse and para-sagittal measurements of corresponding points between the right and left sides of the dental arch in Class II subdivision malocclusions treated with unilateral and bilateral premolar extractions.

H (2) – There are no statistically significant mean differences in dental arch form symmetry in transverse and sagittal dimensions between cases treated with unilateral premolar extractions, and those treated with bilateral premolar extractions.

H (3) – There is no statistically significant mean difference in the magnitude of dental midline deviation relative to the mid-sagittal plane in Class II subdivisions treated with unilateral and bilateral premolar extractions.

2. LITERATURE REVIEW

2.1 Etiology and Location of Asymmetry in Class II Subdivisions

The different and progressive results reported amongst studies on the origin and etiology of a Class II subdivision can be related to the form of diagnostic records studied or the type of radiographic analysis performed. Studies that used frontal photographs (Janson et al., 2007) and dental study models (de Araujo et al., 1994) showed that in the majority of Class II subdivision malocclusions it is primarily the mandibular dental midline that is usually displaced toward the Class II side. Studies that examined two-dimensional radiographs including SMV, PA and lateral cephalograms reported that the principal contributor to a Class II subdivision malocclusion is the distal positioning of the mandibular first molar relative to the maxillary first molar on the Class II side (Alavi et al., 1988; Rose et al., 1994; Janson et al., 2001), but they did not decipher whether the asymmetry was dento-alveolar or skeletal in nature. Mesial positioning of the maxillary first molar in relation to the mandibular first molar on the Class II side was found to be a secondary contributor in these studies.

In 2006, a study published by Azevedo et al. (2006) demonstrated that the components contributing to an asymmetric molar relationship are mainly dentoalveolar. On the other hand, a recent study by Sanders et al. (2010) reports the primary cause may be skeletal. This investigation used CBCT radiographs to assess the skeletal and dental asymmetries in Class II subdivision malocclusions, and findings revealed that the primary etiology of a Class II subdivision malocclusion is an asymmetric mandible which is shorter and more posteriorly positioned on the Class II side. The mandible is deficient either due to a shortened ramal height or a reduction in the length of the body of the mandible on the Class II side. A more recent study published in 2013 by utilized cone-beam computed tomography to analyze the dental and skeletal asymmetries between the Class I and Class II sides in Class II subdivision malocclusions (Minich et al., 2013). Significant differences were found for two skeletal measurements: The maxilla on the Class II side was found to be positioned lateral, further forward and more inferior on the Class II side, while the mandibular dimension from the mandibular foramen to the mental foramen was found to be shorter on the Class II side. Their findings revealed significant dental and skeletal differences between contralateral sides with dental asymmetries responsible for about two thirds of the total asymmetry. Vig and Hewitt (1975) suggested the dentoalveolar region should display a greater level of symmetry than the facial skeleton as the dentoalveolar units are more adaptive in that they can be molded by the surrounding labial and lingual musculature more readily.

2.2 Treatment Approaches for Class II Subdivision Malocclusions

After a comprehensive and accurate diagnosis is performed, the treatment of Class II subdivision malocclusions can be successfully managed orthodontically through a variety of treatment protocols (Janson et al., 2009). A handful of mechanical techniques are available for unilateral distalization of the maxillary posterior segments (Burstone et al, 2000). A clinical case study by Artun et al. (2013) presents an adolescent malocclusion case successfully treated using a unilateral cervical headgear adjusted with the long outer bow on the Class II side, followed by fixed appliances. After four months of compliant headgear wear, a Class I molar relation was established on the affected side with a super CI relation on the contralateral side.

Correction of Class II subdivision malocclusions through the use of functional appliances seems sensible, yet there is insufficient literature on the treatment outcomes using these approaches (Melsen et al., 1986; Miguel and Zanardi, 2008; Paulsen and Karle, 2000; Bock et al., 2013). A study comparing the outcomes of Herbst treatment in Class II patients and Class II subdivision malocclusions showed no difference in the success of treatment outcome, however, a slight overcompensation or Class III tendency of the molar relation was observed on the originally unaffected side in the latter group (Bock et al., 2013).

A conventional approach for correcting anteroposterior discrepancy in dental relations is the use of intermaxillary elastics. Unilateral Class II elastics have been linked with significant side effects depending on the amount and point of application of the force. Among these side effects are skewed arch forms, asymmetric overjet, lower incisor flaring and canting of the occlusal plane from the vertical component of the force (Shroff et al., 1997). Burstone et al. (2000) advise against the use of Class II-Class III and anterior crisscross elastics in asymmetric occlusions that typically present with normal posterior overjet. The unwanted side effects of eruption and occlusal plane canting can lead to instability. The study suggests a more preferable strategy for non-extraction therapy is to move teeth around the arch rather than performing en masse movement of the entire arch.

Dental asymmetries that are a result of altered molar axial inclination can be corrected using unilateral tip-back moments as presented in Shroff et al. (1997). The unilateral distal tipping of the molar on the desired side relies on tip-back moments rather than distal forces. The study reviews appliance design and principles of segmented arch technique that will provide forces in a sequenced and regulated system.

A combined ortho-surgical approach is generally the best treatment option when there are serious skeletal elements accompanying the malocclusion, examples of which would be a retruded mandible or vertical growth pattern (Pinho and Figueiredo, 2011). Asymmetric surgery is required to correct the asymmetric smile that is common to Class II subdivision malocclusions (Pinho and Figueiredo, 2011). There is not a great deal of published research that has studied surgical treatments of Class II subdivisions, but Janson et al. (2009), Kuroda, Murakami, Morishige, and Takano-Yamamoto (2009), as well as Pinho and Figueiredo (2011) investigated the topic. A Class II subdivision clinical case report by Pinho (2012) presents an innovative approach for correcting this type of malocclusion if surgical intervention is refused by the patient. After initial leveling and alignment for twelve months, multiloop edgewise archwire (MEAW) mechanics were employed to modify the occlusal plane and reposition the mandible. Differential MEAW activation and occlusal composite restorations allowed for increase in vertical dimension on the affected side accompanied with short vertical elastics in the anterior area and unaffected side of the dentition.

An ideal treatment method does in fact exist for every kind of Class II subdivision malocclusion and the practitioner should choose the ideal approach as the primary treatment strategy (Janson, Woodside, et al., 2003). It is likely the most overlooked approach for treating a type 1 subdivision is an asymmetric extraction of three premolars, and a single premolar extraction for a type II subdivision followed with space closure with fixed appliances (Turpin, 2005).

2.3 Extraction versus Non-Extraction Therapy

It has been suggested that extraction decisions and pre-treatment Angle classification influence how certain dimensions of the arch change, including anterior arch width (Kim and Gianelly, 2003). The specific nature of these changes reported in literature vary and findings do not necessarily coincide between studies. There is debate regarding whether extraction therapy leads to narrowing of the dental arch and a decrease in smile esthetics.

BeGole et al. (2005) reported significant increase in canine and premolar arch widths in non-extraction arches, and no such expansion was seen in arches treated with premolar extractions. Furthermore, one study of sixty patients split evenly amongst both extraction and non-extraction groups concluded that neither extraction nor non-extraction treatment has a preferential effect on smile esthetics (Kim and Gianelly, 2003). As arch width is an important determinant of smile esthetics and because the arch widths of both groups were essentially equal, the study rejected the assumption that smiles of extraction-treated patients are less esthetic. Bishara et al. (1997) recounted an appreciably bigger increase in arch width at anterior arch positions and at the premolars in extraction groups during the treatment of Class I and Class II division 1 malocclusions compared to non-extraction groups.

A number of conclusions have been reported on the effect of extraction treatment on arch width. Some studies describe a measureable collapse of the arch on the extraction side while others propose there is no difference, and still some who demonstrated the widening of arch. Extraction treatment that results in a significant increase or decrease in arch width results in an altered arch form. It is then within reason to speculate whether extracting a single premolar unilaterally would produce a different response in the arch form between the extraction and non-extraction quadrants.

2.4 Asymmetric Extraction Protocols for Class II Subdivisions

The extraction controversy continues from the early 20th century. Edward H. Angle stressed the necessity of preserving every dental unit in order to obtain facial balance, harmony and esthetics. Consequent research associated with treatment stability contradicted his views and pointed towards the necessity of tooth extractions to treat certain malocclusions. Extraction protocols allowed for correction of dental position asymmetries through controlled and strategic space closure by the orthodontic professional. Over time many have come to look at asymmetric extractions as required and significant in order to fix midline deviation; allow for unilateral change of the posterior teeth; decrease treatment length and tooth movement; enable orthodontic procedures and acquire more lasting and practical outcomes (Melgaco and Araujo, 2012).

Asymmetric orthodontic mechanics can successfully correct minor asymmetries but may not be a practical solution for correcting asymmetries of greater severity levels. Movements are limited in scope and can result in high levels of unwanted side effects if exploited unreasonably. A unilateral extraction may be a viable treatment option in malocclusions of moderate to severe asymmetry in which surgery is contraindicated or rejected by the patient (Struhs, 2005). By creating space asymmetrically, it allows the practitioner to conduct the mechanics of treatment in a symmetrical fashion, thus avoiding many of the side effects encountered when applying asymmetrical mechanics (Lindauer, 1998). In depth analysis of anchorage requirements should be conducted beforehand so that the teeth extracted allow for maximum chances of proceeding with treatment in a symmetric fashion (Lindauer, 1998).

The treatment of Class II subdivision malocclusions with asymmetric extractions can be beneficial and successful for a number of reasons: they maintain existing molar relationships; this results in reduced treatment time; and also leads to a greater ease of midline correction (Turpin, 2005). According to the literature, cases that completed with first permanent molars in a Class II or III relation on one or both sides do not appear to lead to an esthetic or functional problem (Melgaco and Araujo, 2012). Asymmetric extractions allow for the possibility of the rectification of maxillary and mandibular dental midline divergences without canting of the occlusal plane and any undesirable dentoskeletal changes in the frontal plane are avoided. (Turpin, 2005).

As reported by Janson, Woodside, et al. (2003), the success rates of appropriately diagnosed Class II subdivision malocclusions treated with asymmetric three premolar extractions have shown to be more effective than those patients treated with symmetric four premolar extractions. The asymmetric extraction pattern proved to be faster and more effective in attaining dental midline improvement with limited mandibular incisor and soft-tissue retraction. Further studies have shown that the asymmetric extraction protocols preserved the disparities in the anteroposterior positions of right and left, maxillary and mandibular first molars (Janson, Cruz, et al., 2004). No significant skeletal changes or transverse secondary effects could be attributed to asymmetric extractions. This form of treatment generated improvements of "maxillary and mandibular dental midline deviations relative to the midsagittal plane, without canting the occlusal plane or any other investigated horizontal plane" (Janson, Cruz, et al., 2004).

2.5 Analysis of the Dental Arch

Abundant effort has been spent on identifying the ideal form of the dental arch, as it is integral in treatment planning and restoring functional occlusion. The form of the arch was generally depicted in straightforward qualitative expressions such as elliptic, parabolic, and U-shaped, but these descriptive terms are out-of-favor as they were found to be insufficient to accurately define the dental arch. Consequently there has been greater effort to quantify arch forms via the use of linear measurements, with arch width, depth, and circumference being the primary examples, but these measurements do not supply a complete picture of all arch traits. (Muhamad et al., 2014).

This challenge led some to suggest that the ideal method for designating the curvature of the dental arch was by the use of a mathematical curve as it could be fitted to any size or shape of the dental arch. This curve fitting uses a mathematically generated curve that is fitted against dental landmarks in order to produce something which approximates the dental arch curvature. (Muhamad et al., 2014). Mathematical analyses of dental arch configurations concluded that the fourth-order polynomial was the function best suited for this purpose as it could be used to describe the general smooth curvature of the arch. And since the fourth-order polynomial function results in a more naturally smooth curve it can be used to predict an ideal arch for each individual patient. (AlHarbi et al., 2008).

In addition to the fourth-order polynomial, other mathematical models to describe the dental arch have been suggested, including a cubic spline and beta function. The cubic spline method, which analyzed change in dental arch form resulting from orthodontic treatment, was found to satisfactorily model the form of the dental arches (BeGole and Lyew, 1998). The beta function method was also found to reproduce the dental arch, but it does not factor in dental landmarks besides molar width and arch depth and does not take asymmetrical forms into account. While each model was found to have advantages and disadvantages, they were not able to exactly delineate the shape of the dental arch curvature, but the fourth-order polynomial functions are generally seen to more effective in defining the dental arch compared to the cubic spline or the beta function methods (AlHarbi et al, 2008).

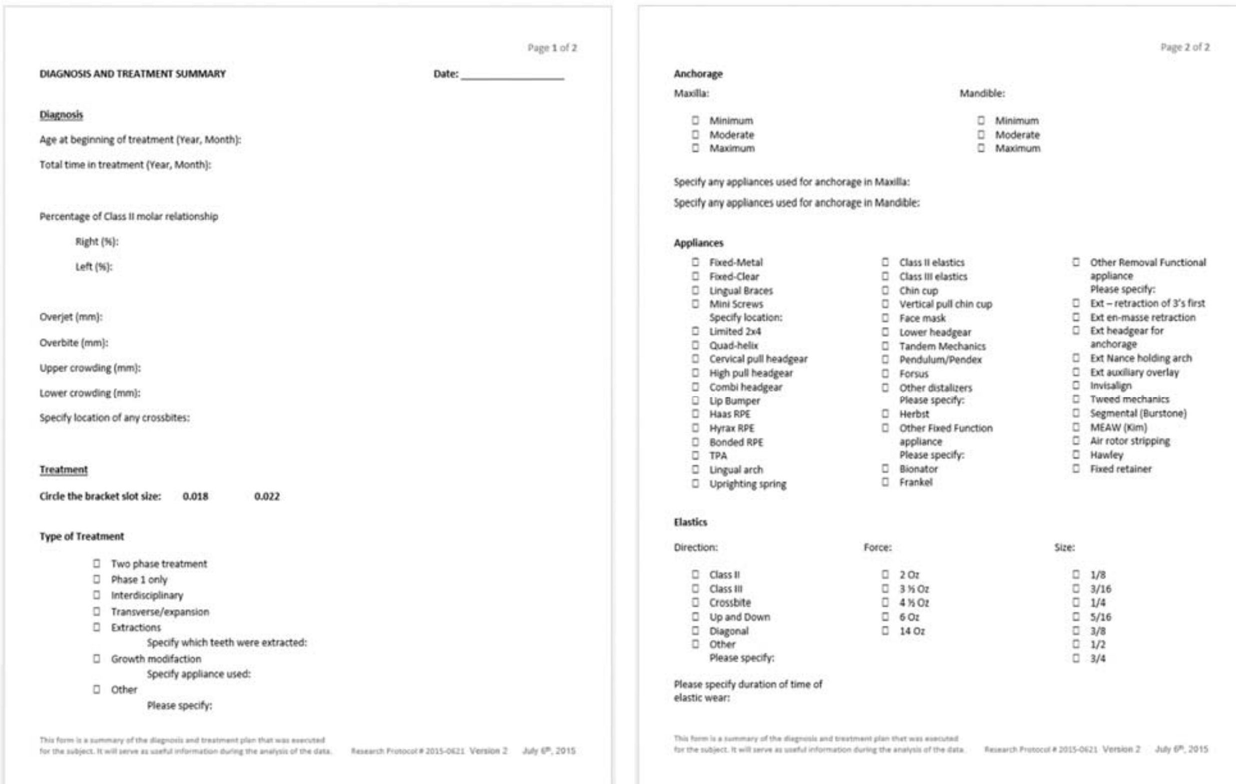
3. MATERIALS AND METHODS

This study was approved by the University of Illinois at Chicago (UIC) Institutional Review Board, Office of the Protection of Research Subjects (OPRS), on July 22nd, 2015, IRB Protocol #2015-0621 (Appendix A).

3.1 De-Identification

The honest broker searched through pre-existing patient records at the University of Illinois at Chicago, Department of Orthodontics, and identified Class II subdivision malocclusions treated with unilateral and bilateral premolar extractions. The honest broker created electronic file folders for those subjects who fit the inclusion criteria and named the folders according to a randomly assigned code obtained from a randomization table.

Dental study models and intraoral photographs of the selected subjects were de-identified by the honest broker. Pre-existing initial and final dental study models were saved in STL (stereo lithography) file format under the respective folder. A snapshot of the initial and final photographs of the teeth present in Dolphin Imaging Software was captured and saved as JPEG images under the respective folder. De-identified summaries of the diagnostic and treatment record notes void of any HIPAA identifiers were provided by the honest broker. The honest broker used Microsoft Office Word software to complete the diagnosis and treatment summary form (see Figure 1) by referring to the information present in Axium in regards to the diagnosis and treatment plan executed. The files were saved in DOC (document) file format under the respective folder. These individual files were named without any associated identifiers. Each folder consisted of five individual files named as follows: “InitialModel.stl”, “FinalModel.stl”, “InitialPhotos.jpg”, “FinalPhotos.jpg” and “Summary.doc.”



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DIAGNOSIS AND TREATMENT SUMMARY **Date:** ____________

Diagnosis

Age at beginning of treatment (Year, Month):

Total time in treatment (Year, Month):

Percentage of Class II molar relationship

Right (%):

Left (%):

Overjet (mm):

Overbite (mm):

Upper crowding (mm):

Lower crowding (mm):

Specify location of any crossbites:

Treatment

Circle the bracket slot size: 0.018 0.022

Type of Treatment

- ☐ Two phase treatment
- ☐ Phase 1 only
- ☐ Interdisciplinary
- ☐ Transverse/expansion
- ☐ Extractions
  Specify which teeth were extracted:
- ☐ Growth modifaction
  Specify appliance used:
- ☐ Other
  Please specify:

This form is a summary of the diagnosis and treatment plan that was executed for the subject. It will serve as useful information during the analysis of the data. Research Protocol # 2015-0621 Version 2 July 6th, 2015

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Anchorage

Maxilla:

- ☐ Minimum
- ☐ Moderate
- ☐ Maximum

Mandible:

- ☐ Minimum
- ☐ Moderate
- ☐ Maximum

Specify any appliances used for anchorage in Maxilla:

Specify any appliances used for anchorage in Mandible:

Appliances

- ☐ Fixed-Metal
- ☐ Fixed-Clear
- ☐ Lingual Braces
- ☐ Mini Screws
  Specify location:
- ☐ Limited 2x4
- ☐ Quad-helix
- ☐ Cervical pull headgear
- ☐ High pull headgear
- ☐ Combi headgear
- ☐ Lip Bumper
- ☐ Haas RPE
- ☐ Hyrax RPE
- ☐ Bonded RPE
- ☐ TPA
- ☐ Lingual arch
- ☐ Uprighting spring
- ☐ Class II elastics
- ☐ Class III elastics
- ☐ Chin cup
- ☐ Vertical pull chin cup
- ☐ Face mask
- ☐ Lower headgear
- ☐ Tandem Mechanics
- ☐ Pendulum/Pendex
- ☐ Forsus
- ☐ Other distalizers
  Please specify:
- ☐ Herbst
- ☐ Other Fixed Function appliance
  Please specify:
- ☐ Bionator
- ☐ Frankel
- ☐ Other Removal Functional appliance
  Please specify:
- ☐ Ext – retraction of 3’s first
- ☐ Ext en-masse retraction
- ☐ Ext headgear for anchorage
- ☐ Ext Nance holding arch
- ☐ Ext auxiliary overlay
- ☐ Invisalign
- ☐ Tweed mechanics
- ☐ Segmental (Burstone)
- ☐ MEAW (Kim)
- ☐ Air rotor stripping
- ☐ Hawley
- ☐ Fixed retainer

Elastics

Direction:

- ☐ Class II
- ☐ Class III
- ☐ Crossbite
- ☐ Up and Down
- ☐ Diagonal
- ☐ Other
  Please specify:

Force:

- ☐ 2 Oz
- ☐ 3 ½ Oz
- ☐ 4 ½ Oz
- ☐ 6 Oz
- ☐ 14 Oz

Size:

- ☐ 1/8
- ☐ 3/16
- ☐ 1/4
- ☐ 5/16
- ☐ 3/8
- ☐ 1/2
- ☐ 3/4

Please specify duration of time of elastic wear:

This form is a summary of the diagnosis and treatment plan that was executed for the subject. It will serve as useful information during the analysis of the data. Research Protocol # 2015-0621 Version 2 July 6th, 2015

Figure 1. Standard summary form of the diagnosis and treatment.

No information that permits re-identification was disclosed to any member of the research committee. The master re-identification key was destroyed by the honest broker before the de-identified folders were provided to the research committee.

3.2 Study Design and Data Acquisition

When the data source was made available to the principal investigator, neither the investigator nor the source were able to directly or indirectly identify the subject. The de-identified models, photographs and diagnostic/treatment summary forms were examined by the principal investigator to test for suitability of the subjects according to the inclusion criteria.

From the sample of subjects provided by the honest broker, thirteen subjects met the inclusion criteria for the testing group and twenty for the control group. These subjects were divided into two groups:

1. Unilateral premolar extraction (Testing Group).
2. Bilateral premolar extraction (Control Group).

The STL file of the post-treatment digital model was then imported into Geomagic® Control™ 14 Software (3D Systems Inc., Rock Hill, SC, USA®) for construction of reference planes and landmark identification. The facial axis (FA) points were digitized for each tooth on the virtual models, and the three-dimensional coordinates of these landmarks were recorded and imported into MATLAB™ mathematical software (MATLAB™ 8.4 (2014b), MathWorks, Natick, MA, USA) for analysis.

3.3 Geomagic™ Software

Geomagic® Control™ is an industry leading 3D metrology solution and automation platform. While it is a tool most commonly used in manufacturing, including medical manufacturing, it proved very useful in this project. Its use in the medical field centers on checking new medical implants for accurateness or appraising and evaluating worn parts to improve designs. Geomagic® Control™ also pairs with medical CT scanning in order to check the progress of remedial surgery – like orthodontic procedures – quickly and painlessly. It provides robust geometric dimensioning and tolerancing (GD&T) functionality, which is a system for describing and conveying engineering tolerances. It employs a symbolic language on engineering diagrams and simulated 3D solid models that unambiguously describes nominal geometry and its allowable variation. Geomagic® Control™ also provides: standard dimensioning; reference geometry creation; probing and attribute tools for swift reference geometry formation with mouse or probing device; automation platform and scripting, including multiple inspection functionalities; and 2D and 3D dimensioning. As seen in Figure 2, the intuitive user interface and selection tools make the software user-friendly.

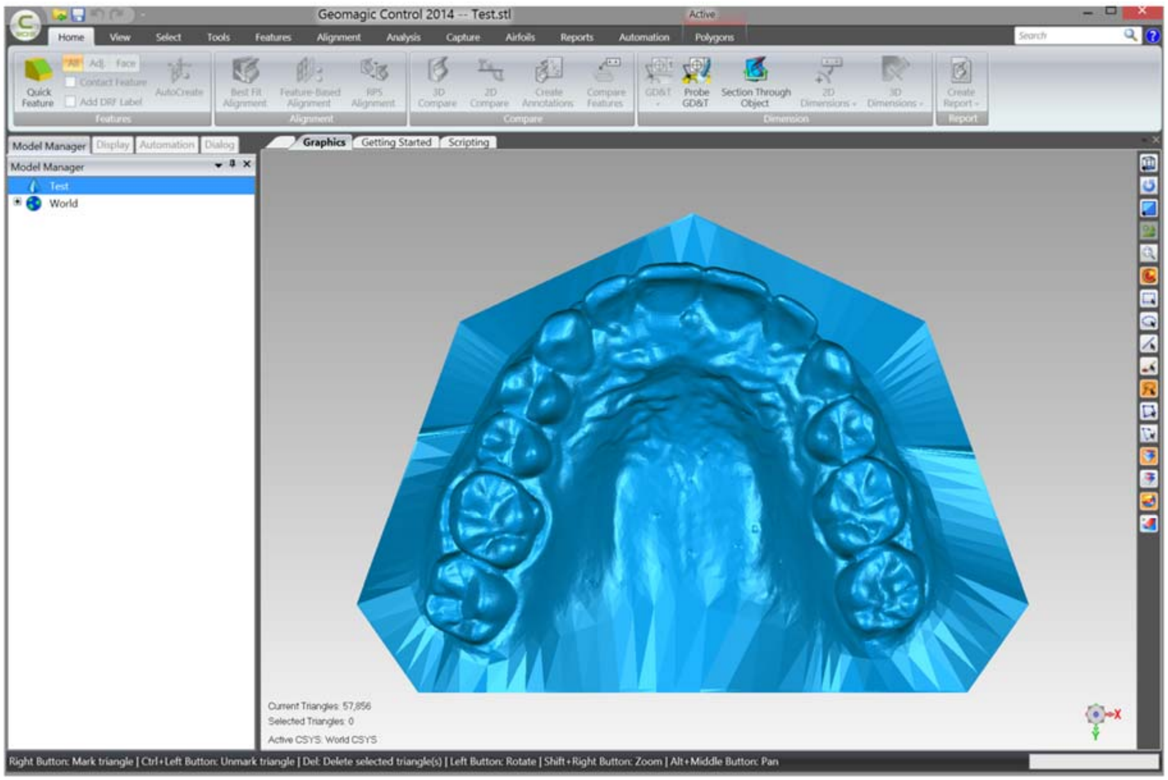

Figure 2. Geomagic™ Software user-interface with imported STL file of an upper arch.

3.3.1 Construction of Reference Planes

The horizontal (XY) plane was constructed by digitizing the FA points from first molar to first molar and constructing a best fitting plane that runs through these points, as seen in Figure 3. The facial axis (FA) point is defined as the center of the facial axis of the clinical crown. For the first molar, the FA point is defined as the point midway occluso-gingival along the mesio-buccal groove. Geomagic™ does a best fit through these points by ignoring the outliers and averaging the rest of the points. Figure 4 displays the XY plane from two different angles.

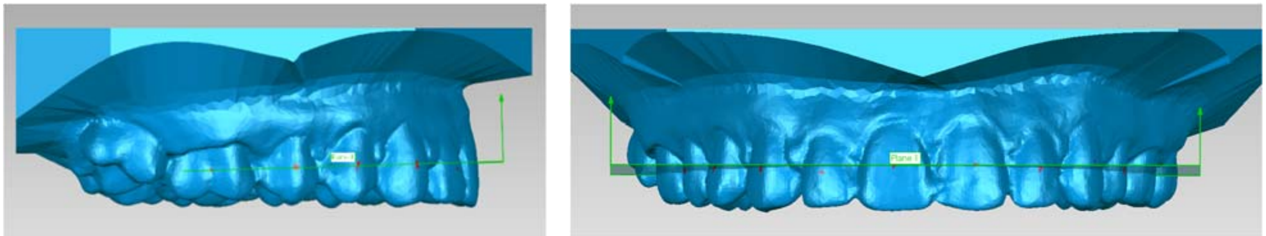

Figure 3. The best fitting plane running through the FA points selected on the 3D virtual models: A, right buccal view; B, frontal view.

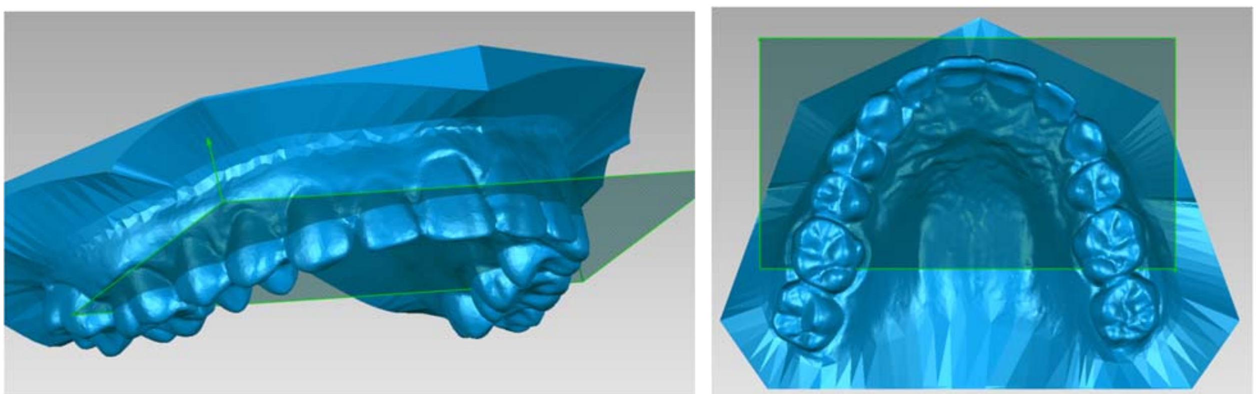

Figure 4. The horizontal (XY) plane: A, angular view; B, occlusal view.

For the construction of the mid-sagittal plane (YZ) plane, two points were selected to create a line (y-axis) running along the anteroposterior direction. The midpoint between the medial ends of the first palatine rugae was selected as the anterior point, and the most posterior point visible on the midpalatal raphe was chosen as the posterior point. The YZ-plane was constructed running through this line, perpendicular to the XY-plane. The YZ-plane can be seen in Figure 5 from two different angles.

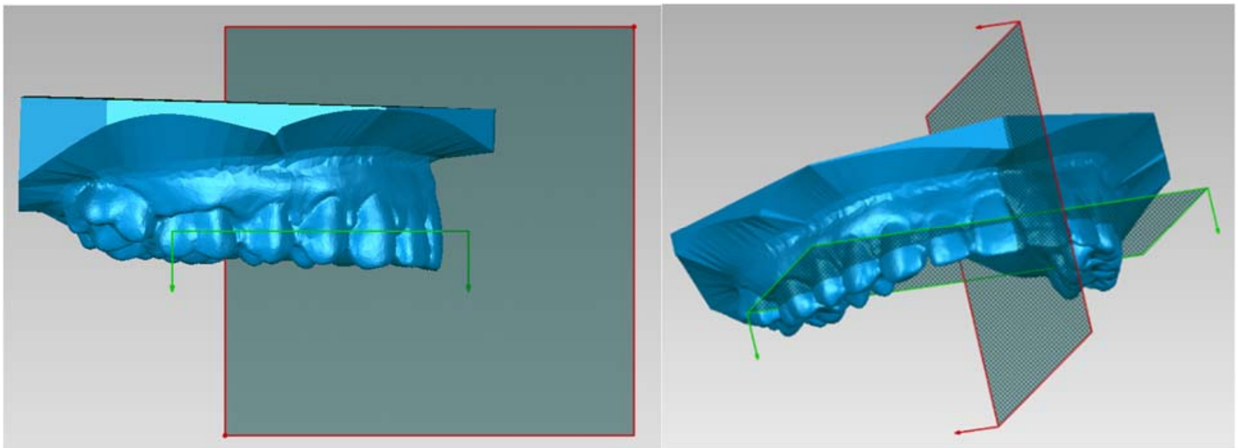

Figure 5. The mid-sagittal (YZ) plane: A, right buccal view; D, angular view.

For the construction of the coronal (XZ) plane, a point was selected in the middle of the incisive papilla (anterior-posteriorly) that falls on the y-axis line. The plane was constructed perpendicular to the other two planes running through this point. Two different angles of the XZ plane are displayed in Figure 6.

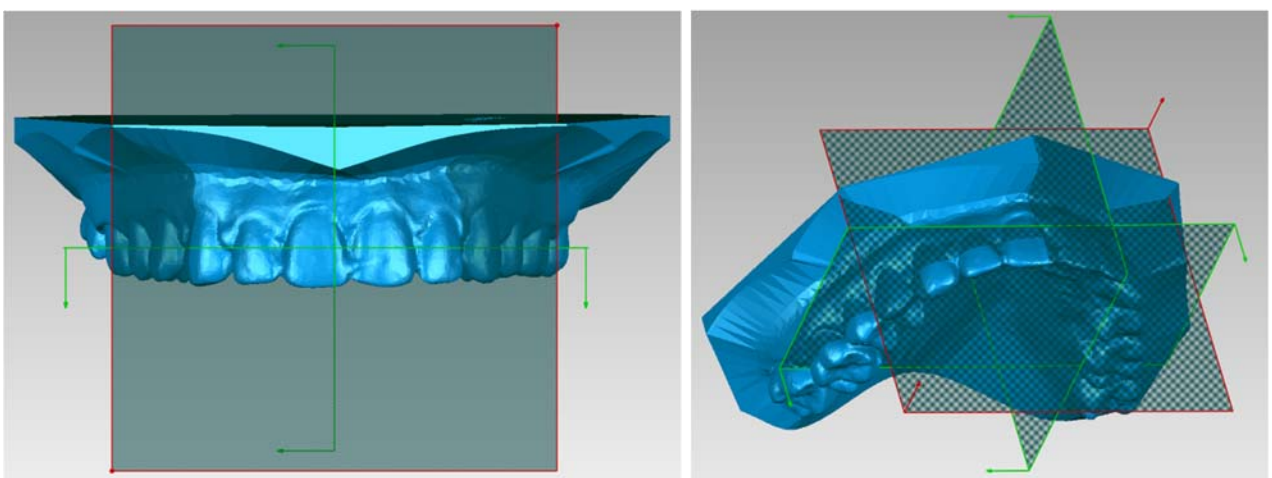

Figure 6. The coronal (XZ) plane: A, frontal view; B, angular view.

The coordinate grid system in Geomagic™ is aligned with the constructed three planes of reference with the origin at the intersection of these planes. The grid can be seen in the background in the background of Figure 7.

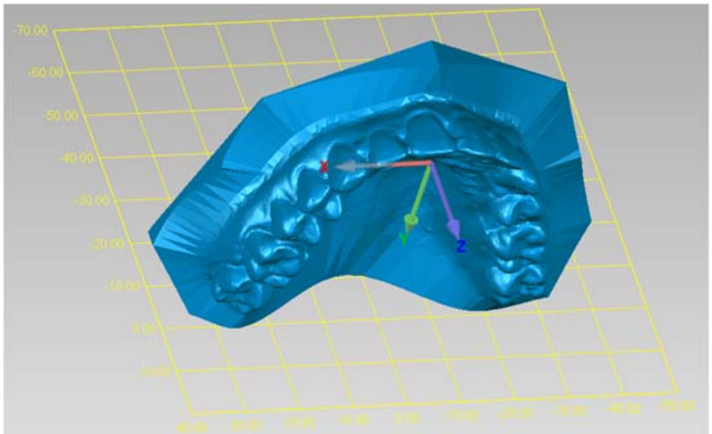

Figure 7. The coordinate grid system aligned to the constructed planes of reference.

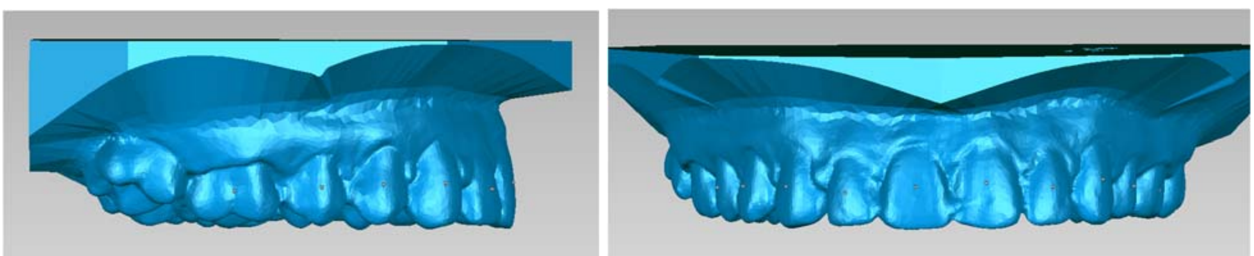

Figure 8. The FA points digitized on the 3D virtual models: A, right buccal view; B, frontal view.

Completion of the reference plane construction and coordinate grid system alignment brings us to the stage of landmark digitization. The point coordinate tool in Geomagic™ was used to manually select the FA points from the right to the left first molar as seen in Figure 8. The coordinate values of these digitized points were obtained and exported to storage files for further analysis.

3.4 MATLAB™ Software

MATLAB™ is a complex language and software used by engineers and scientists that facilitates the investigation and visualization of ideas. It enables collaboration across diverse disciplines, including signal and image processing, communications, control systems, and computational finance. MATLAB™ provides an interactive and user-friendly environment for iterative exploration, design, and problem solving. The MATLAB™ user-interface is shown in Figure 9. Its arithmetical functions include: linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration, and answering normal differential equations. MATLAB™ also offers integrated graphics for visualizing data and instruments for generating custom plots which includes built-in 2-D and 3-D plotting functions, as well as volume visualization functions. These tools can be used to envision and comprehend data and convey results. Plots can be modified both interactively or programmatically.

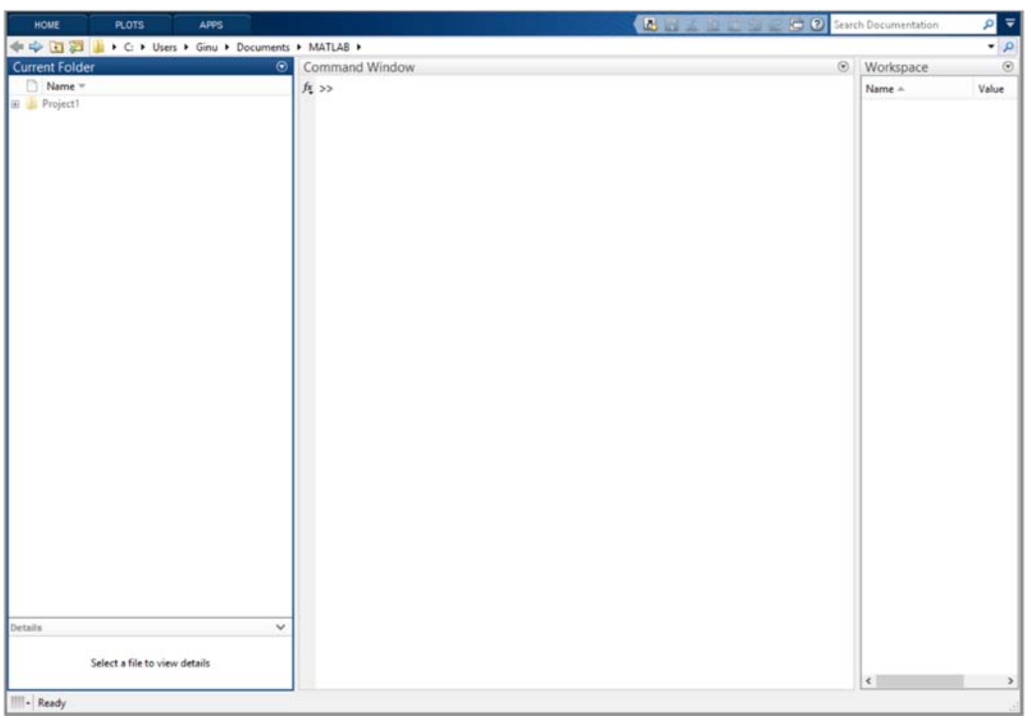

Figure 9. MATLAB™ interactive user-interface.

3.4.1 Raw Data Collection

Coordinate points of the dental landmarks were imported into MATLAB™ mathematical software (MATLAB™ 8.4 (2014b), MathWorks, Natick, MA, USA) in which a coded program is designed to use these coordinates and construct the best fitting curve that is representative of the dental arch form. The code can be viewed in the Appendix. The dental arch form is expressed as a quadratic polynomial expression. The algorithm used by MATLAB™ for polynomial curve is a best fit in a least-squares sense for the data in y. The program minimizes the sum of squared distances between observed and fitted y-values. An example of a best fit curve generated by the program designed in MATLAB™ can be seen in Figure 10. The best fitting graph for each subject was saved in the appropriate folder.

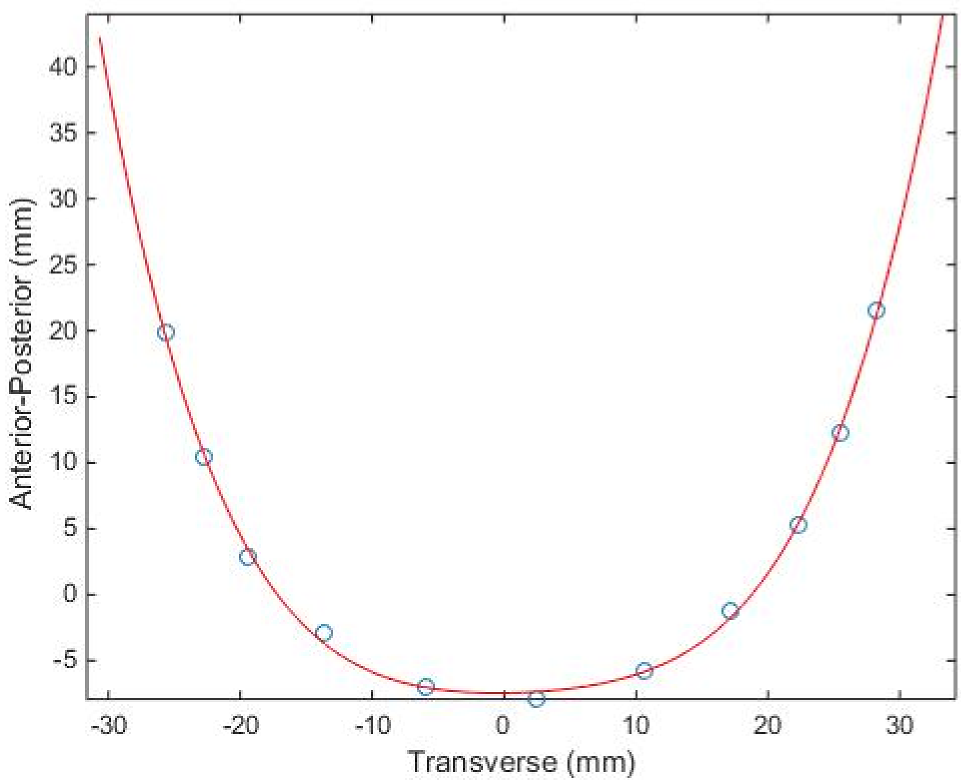

Figure 10. Example of a best fitting curve constructed in MATLAB™ Software.

The software program is designed to make measurements in the transverse and para-sagittal dimensions for symmetry assessment of the constructed dental arch form.

3.4.2 Transverse Measurements

For analysis in the transverse dimension, the distance from the minimum to the maximum y-value was divided into fifteen equal segments. Data collection began at the subsequent y-value following the minimum y-value, for a total of fifteen pre-selected y-values. The values of x on either side of these pre-selected y-values were interpolated. The x value is extrapolated for the last point on the side of the arch that runs shorter. The right and left values of x at each pre-selected y-value and the difference between them is reported in the results section of this paper.

3.4.3 Para-Sagittal Measurements

For analysis in the sagittal dimension, MATLAB™ identified the narrower side of the arch at the maximum y-value and divided the distance into ten equal segments. The segment size was calculated and this distance was used to create segments of equal sizes in the opposite or wider side of the arch. MATLAB™ performed a comparison between the numbers of segments on each side of the arch, and eliminated the extra segment on the wider side to give an equal number of segments of equal sizes on both sides of the arch. Data collection began in the right and left direction following x=0, for a total of ten pre-selected x-values on each side of the arch. The values of y on both sides of the arch were interpolated at these pre-selected x-values. These y-values and the difference between them were reported in the results section of this paper.

3.4.4 Arch Form Divisions

For the purposes of describing the arch form in this study, each maxillary dental arch was divided into segments of five in the transverse and sagittal dimensions, as diagramed in Figure 11. The segments are labelled as follows: anterior, anterior-middle, middle, posterior-middle, and posterior. The fifteen measurements taken in the transverse dimension were divided into groups of three and these measurements were averaged to give a total of five values which were related to their corresponding segment area on the arch. Similarly, the ten measurements taken in the sagittal dimension were divided into groups of two and these measurements were averaged to give a total of five values which were related to their corresponding areas on the arch.

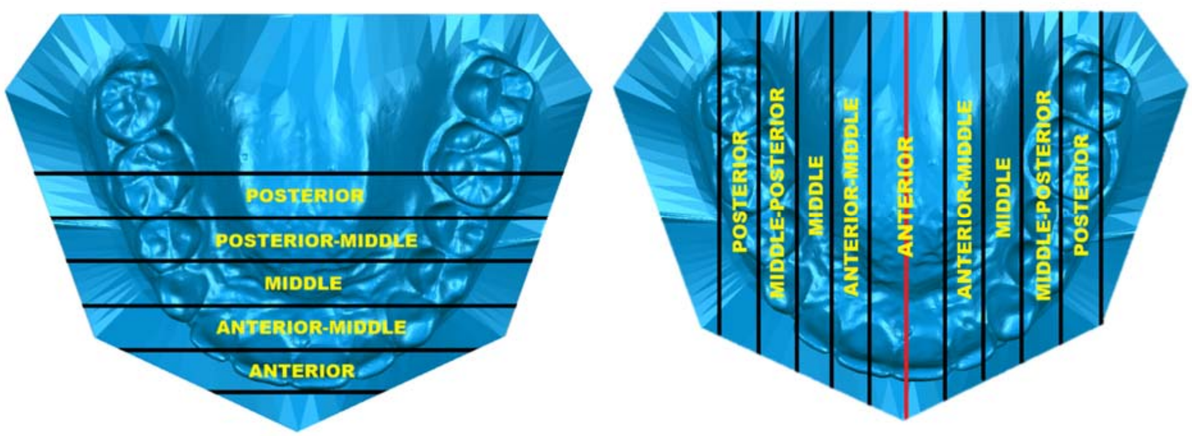

Figure 11. Arch Form Divisions: A, Transverse Dimension; b**,** Sagittal Dimension.

3.5 <u>Dental Midline</u>

To study the deviation of the dental midline relative to the mid-palatal raphe in the transverse dimension, the absolute x-values of the FA-points of the upper central incisors were recorded for each subject. In the unilateral extraction group, FA_{x1} and FA_{x2} denote the absolute x-values of the digitized FA points of the maxillary central incisors on the non-extraction and extraction halves of the arch respectively. The average of these values was computed and the distance of this average value from the Y-axis was calculated.

3.6 Superimpositions

Arches from each group were superimposed in Geomagic™ software on the constructed axes and planes to create one single arch that was a qualitative representation of the average post-treatment dental arch form of all arches within each group.

Those arches with unilateral extractions performed on the left side were flipped on the YZ-plane to create a mirror model. This ensured uniformity of the extraction region before superimpositions are done.

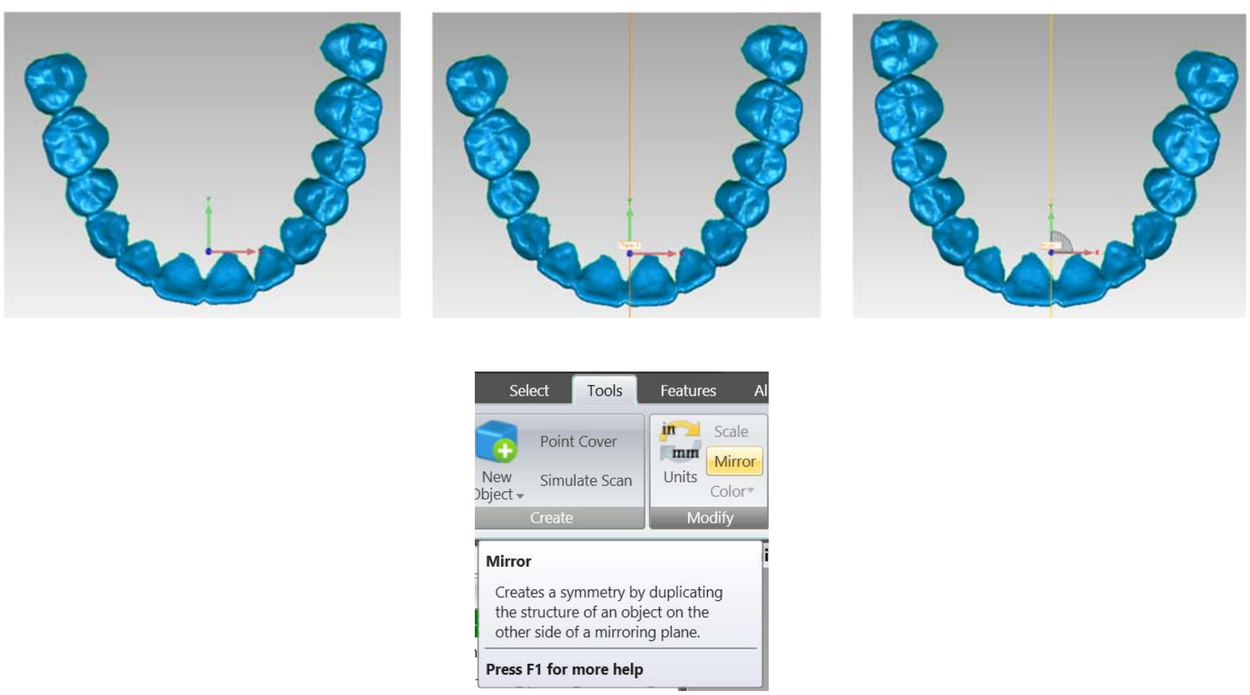

Figure 12. Construction of a mirror model: A, Original Arch; B, Original Arch with YZ Reference Plane; C, Mirrored Arch with YZ reference plane; D, Mirror Tool in Geomagic™.

Gingival and palatal tissues were manually selected and eliminated for each arch in advance to avoid introduction of extra noise and distortion in our data processing. This process can be visualized in Figure 13. All fixed lingual retainers were also manually selected for elimination for similar reasons, and the void was filled using a new mesh that matches the curvature of the surrounding mesh (i.e. curvature of the lingual surfaces of the anterior teeth). This process can be visualized in Figure 14. Third molars were not included in the superimpositions. The constructed average arch from each group was quantitatively analyzed in Geomagic™ and MATLAB™ software using methods similar to those described earlier.

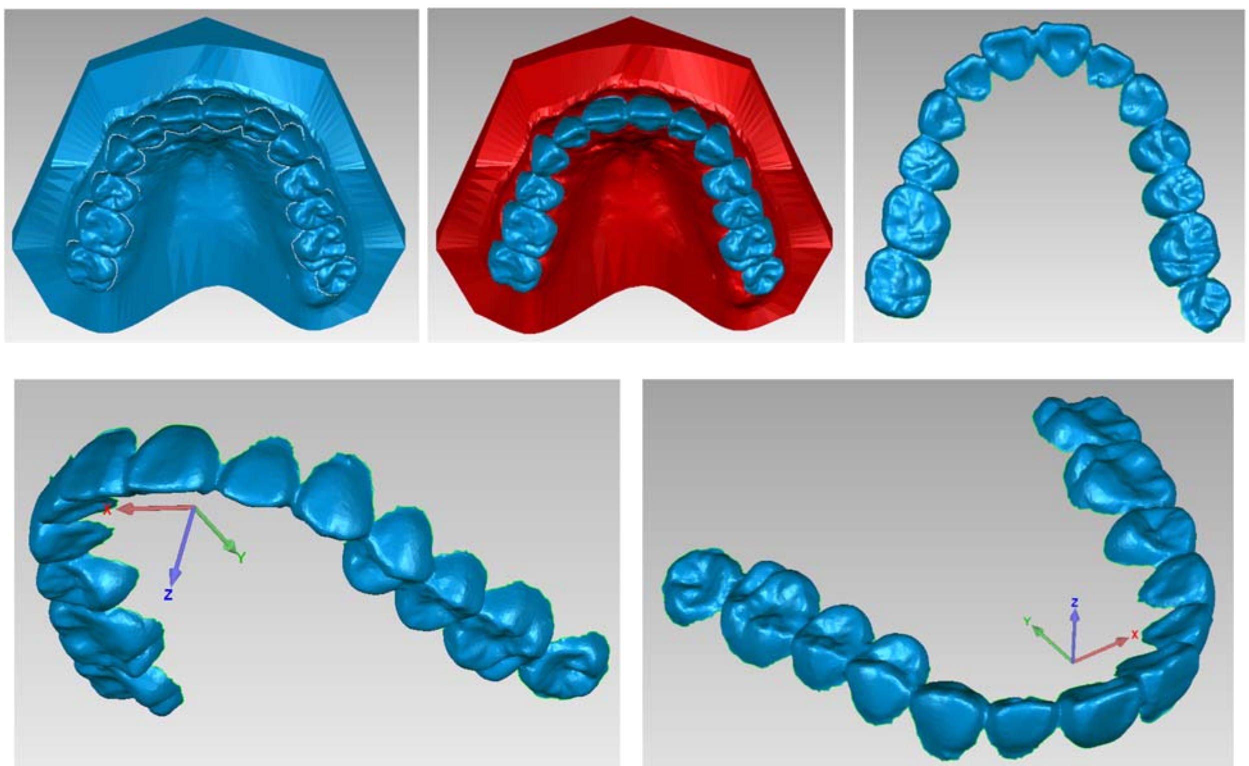

Figure 13. Removal of gingival and palatal tissues: A, Manual division of dentition from surroudings; B, Selection of surrouding structures; C, Deletion of surrouding structures; D and E, Dentition with reference planes from two angular views.

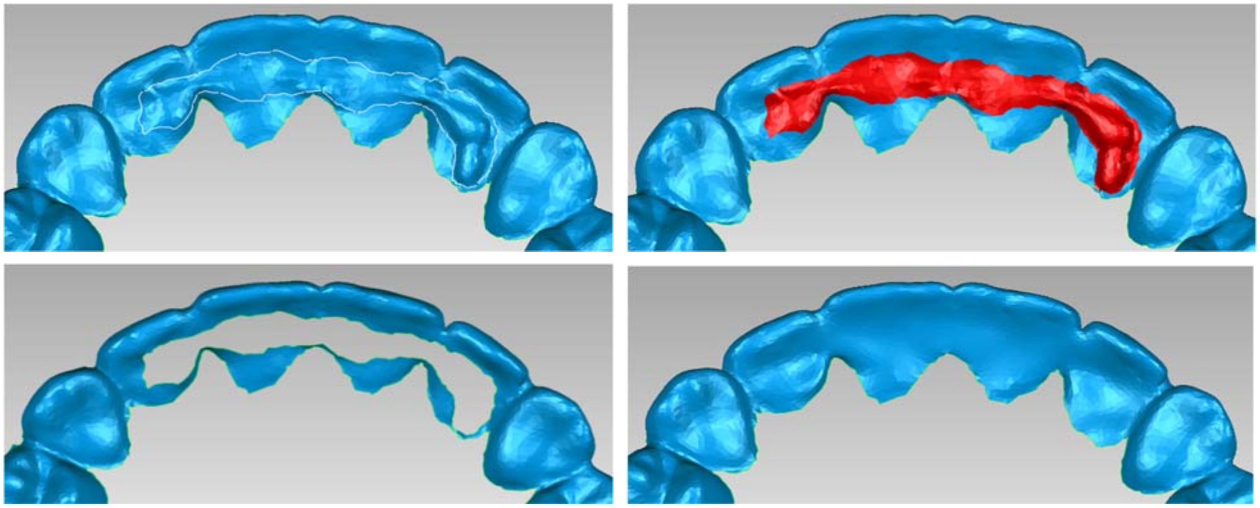

Figure 14. Elimination of fixed lingual retainers: A, Manual division of fixed lingual retainer from dentition; B, Selection of fixed lingual retainer; C, Deletion of fixed lingual retainer; D, New mesh filling the hole.

3.7 Inclusion & Exclusion Criteria

For the purposes of this study, the criteria to classify as a Class II subdivision malocclusion subject was defined as Angle Class I molar relationship on one side of the dentition with at least half step Angle Class II molar relationship on the contralateral side. Subjects were limited solely to those who received extractions in the maxillary arch. It was necessary that subjects included in the study had most treatment records available. This included pre- and post-treatment intraoral photographs of the dentition, pre- and post-treatment digital models, and diagnostic and treatment record notes. Patients with lateral mandibular functional or habitual shifts (noted from a combination of photos, clinical history and diagnostic notes) were excluded from the study. Any subjects with significant contralateral tooth size discrepancies (i.e. unilateral peg lateral), a significant number of malformed or missing teeth (excluding third molars), or teeth with extensive restorations or gross decay were excluded. Individuals with cleft lip and palate, facial trauma, severe facial asymmetries or any syndromes associated with craniofacial deformities were excluded. Any cases debonded before achieving ideal occlusion were also removed from the sample.

3.8 Statistical Analysis

To evaluate intra-operator reliability of construction of reference planes and dental landmark identification, five digital models were randomly selected and reassessed 2 weeks later by the same operator. The planes were re-constructed and the FA-points were re-digitized to obtain x, y and z coordinates. Inter-operator reliability was examined between two operators.

Intra-class correlation coefficient was used to test the intra- and inter-operator reliability.

The distribution of the raw data was investigated by Shapiro-Wilk test of normality. Student t-tests were used to test the mean difference within each experimental group and mean differences between the two experimental groups for all the variables involved in the study. Statistical significance was set at 0.05. Data analysis was performed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp.)

4. RESULTS

4.1 Data Analysis

Intra- and inter-class correlation coefficient (ICC) showed to be higher than 0.95 for all the variables involved in the study and showed good support for the reliability of the method used in this study.

All the variables involving arch form (transverse and sagittal) measurements in the study showed to be normally distributed according to the Shapiro-Wilk test of normality.

Paired t-tests were performed to test the mean difference between corresponding values on the right and left sides of the arch within each experimental group. Independent student t-tests were performed to test the mean difference between testing and control groups of the variables involved in the study.

4.2 Arch Form

4.2.1 Comparison of Corresponding Transverse and Sagittal Measurements within the Unilateral Extraction Group

The mean values of x obtained from averaging three points on the non-extraction and extraction sides of the arch at each segment are reported in Table I for the measurements made in the transverse dimension. The mean y-values obtained from averaging three points on the non-extraction and extraction sides of the arch at each segment are reported in Table II for the measurements made in the sagittal dimension. These tables can be found in the appendix.

Paired sample t-tests were performed to assess the mean difference in corresponding transverse and sagittal measurements between right and left sides of the dental arch in cases treated with a unilateral premolar extraction.

4.2.1.1 Transvere Measurements

The results indicate that three of the variables in the study, or area segments of the arch, show statistically significant mean differences with p-values ranging from 0.001 to 0.033. These areas include the anterior, anterior-middle and middle segments of the arch in the transverse dimension. The middle-posterior and posterior areas of the arch show no statistically significant mean differences, p-value > 0.05. Based on this, the study rejects the null hypothesis that the distances of all corresponding points between the right and left sides of the dental arch are approximately the same in the transverse dimension for those patients treated with unilateral premolar extractions.

TABLE III. PAIRED T-TEST RESULTS FROM THE COMPARISON OF TRANSVERSE MEASUREMENTS WITHIN THE UNILATERAL EXTRACTION GROUP.

Variables		N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Non-Extraction	13	15.0886	1.16548	.32325	.56577	1.81300	.001
	Extraction	13	13.8992	.86966	.24120			
Anterior-Middle	Non-Extraction	13	20.3564	1.00828	.27965	.25888	1.49748	.009
	Extraction	13	19.4782	.79921	.22166			
Middle	Non-Extraction	13	23.4077	.98992	.27455	.07487	1.44872	.033
	Extraction	13	22.6459	.96014	.26629			

Middle-Posterior	Non-Extraction	13	25.6592	1.01978	.28283	-.04074	1.43225	.062
	Extraction	13	24.9634	1.11942	.31047			
Posterior	Non-Extraction	13	27.4747	1.06798	.29620	-.12132	1.42477	.091
	Extraction	13	26.8230	1.25831	.34899			

*p-values statistically significant at $\alpha \leq 0.05$.

4.2.1.2 Para-Sagittal Measurements

The results indicate that four of the variables in the study, or area segments of the arch, show statistically significant mean differences with p-values ranging from 0.01 to 0.045. These areas include the anterior, anterior-middle, middle and middle-posterior segments of the arch in the sagittal dimension. The posterior area of the arch shows no statistically significant mean difference, p-value > 0.05. Based on this, the study rejects the null hypothesis that the distances of all corresponding points between the right and left sides of the dental arch in the sagittal dimension are approximately the same for those patients treated with unilateral premolar extractions. Table IV summarizes the descriptive statistics and the test results.

TABLE IV. PAIRED T-TEST RESULTS FROM THE COMPARISON OF PARA-SAGITTAL MEASUREMENTS WITHIN THE UNILATERAL EXTRACTION GROUP.

Variables		N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Non-Extraction	13	-7.8336	2.19102	.60768	-.37123	-.00517	.045
	Extraction	13	-7.6454	2.24374	.62230			
Anterior-Middle	Non-Extraction	13	-6.8981	2.25068	.62423	-.77171	-.03816	.033
	Extraction	13	-6.4932	2.04103	.56608			

Middle	Non-Extraction	13	-4.0527	2.46881	.68472	-1.39354	-.39365	.002
	Extraction	13	-3.1591	2.27104	.62987			
Middle-Posterior	Non-Extraction	13	2.7053	2.76855	.76786	-2.28979	-.35802	.011
	Extraction	13	4.0292	2.02210	.56083			
Posterior	Non-Extraction	13	15.6062	3.79792	1.05335	-4.67485	.08125	.057
	Extraction	13	17.9030	2.00350	.55567			

*p-values statistically significant at α ≤ 0.05.

A clustered bar chart was created to provide a visual representation of the discrepancy between non-extraction and extraction sides of the arch at the various segments in those cases treated with a unilateral premolar extraction. The discrepancies present in both the transverse and sagittal dimensions are represented Figure 15.

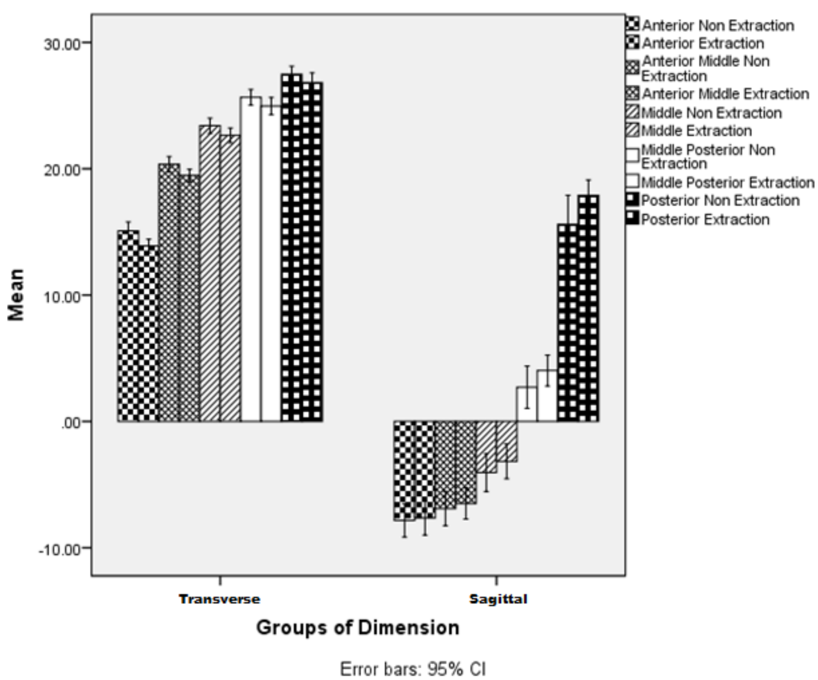

Figure 15. Clustered bar chart of arch form discrepancy present in cases treated with a unilateral premolar extraction.

4.2.2 Comparison of Corresponding Transverse and Sagittal Measurements within the Bilateral Extraction Group

The mean values of x obtained from averaging three points on the right and left sides of the arch at each segment are reported in Table V for the measurements made in the transverse dimension. The mean values of y obtained from averaging three points on the right and left sides of the arch at each segment are reported in Table VI for the measurements made in the sagittal dimension. These tables can be found in the appendix.

Paired sample t-tests were performed to assess the mean difference in corresponding transverse and sagittal measurements between right and left sides of the dental arch in cases treated with bilateral premolar extractions.

4.2.2.1 Transverse Measurements

The results indicate that no variables in the study, or segments of the arch, show statistically significant mean differences, p-value > 0.05. Based on this, the study accepts the null hypothesis that the distances of all corresponding points between the right and left sides of the dental arch are approximately the same in the transverse dimension for those patients treated with bilateral premolar extractions. Table VII summarizes the descriptive statistics and the test results.

TABLE VII. PAIRED T-TEST RESULTS FROM THE COMPARISON OF TRANSVERSE MEASUREMENTS WITHIN THE BILATERAL EXTRACTION GROUP.

Variables		N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Left	20	13.5142	1.30257	.29126	-.71535	.16159	.202
	Right	20	13.7911	1.20613	.26970			
Anterior-Middle	Left	20	18.9221	1.03062	.23045	-.35700	.00365	.054
	Right	20	19.0988	1.01283	.22648			
Middle	Left	20	22.0457	.99857	.22329	-.27846	.01353	.073
	Right	20	22.1782	.94290	.21084			
Middle-Posterior	Left	20	24.3429	1.05182	.23519	-.27190	.05876	.193
	Right	20	24.4495	.94771	.21191			
Posterior	Left	20	26.1905	1.13515	.25383	-.28036	.10210	.342
	Right	20	26.2796	.99149	.22170			

*p-values statistically significant at $\alpha \leq 0.05$.

4.2.2.2 Para-Sagittal Measurements

The results indicate that no variables in the study, or segments of the arch, show statistically significant mean differences, p-value > 0.05. Based on this, the study accepts the null hypothesis that the distances of all corresponding points between the right and left sides of the dental arch in the sagittal dimension are approximately the same for those patients treated with bilateral premolar extractions. Table VIII summarizes the descriptive statistics and the test results.

TABLE VIII. PAIRED T-TEST RESULTS FROM THE COMPARISON OF TRANSVERSE MEASUREMENTS WITHIN THE BILATERAL EXTRACTION GROUP.

Variables		N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Left	20	-7.5971	1.09339	.24449	-.07279	17955	.387
	Right	20	-7.6504	1.06751	.23870			
Anterior-Middle	Left	20	-6.5055	1.09043	.24383	-.12982	.37336	.324
	Right	20	-6.6273	.98915	.22118			
Middle	Left	20	-3.6537	1.16486	.26047	-.09998	.46707	.191
	Right	20	-3.8372	.99809	.22318			
Middle-Posterior	Left	20	2.5299	1.23340	.27580	-.03573	.46260	.089
	Right	20	2.3164	1.15173	.25753			
Posterior	Left	20	14.3159	1.85821	.41551	-.23793	.78205	.278
	Right	20	14.0438	2.13358	.47708			

*p-values statistically significant at $\alpha \leq 0.05$.

A clustered bar chart was created to provide a visual representation of the discrepancy between right and left sides of the arch at the various segments in those cases treated with bilateral premolar extractions. The discrepancies present in both the transverse and sagittal dimensions are represented Figure 16.

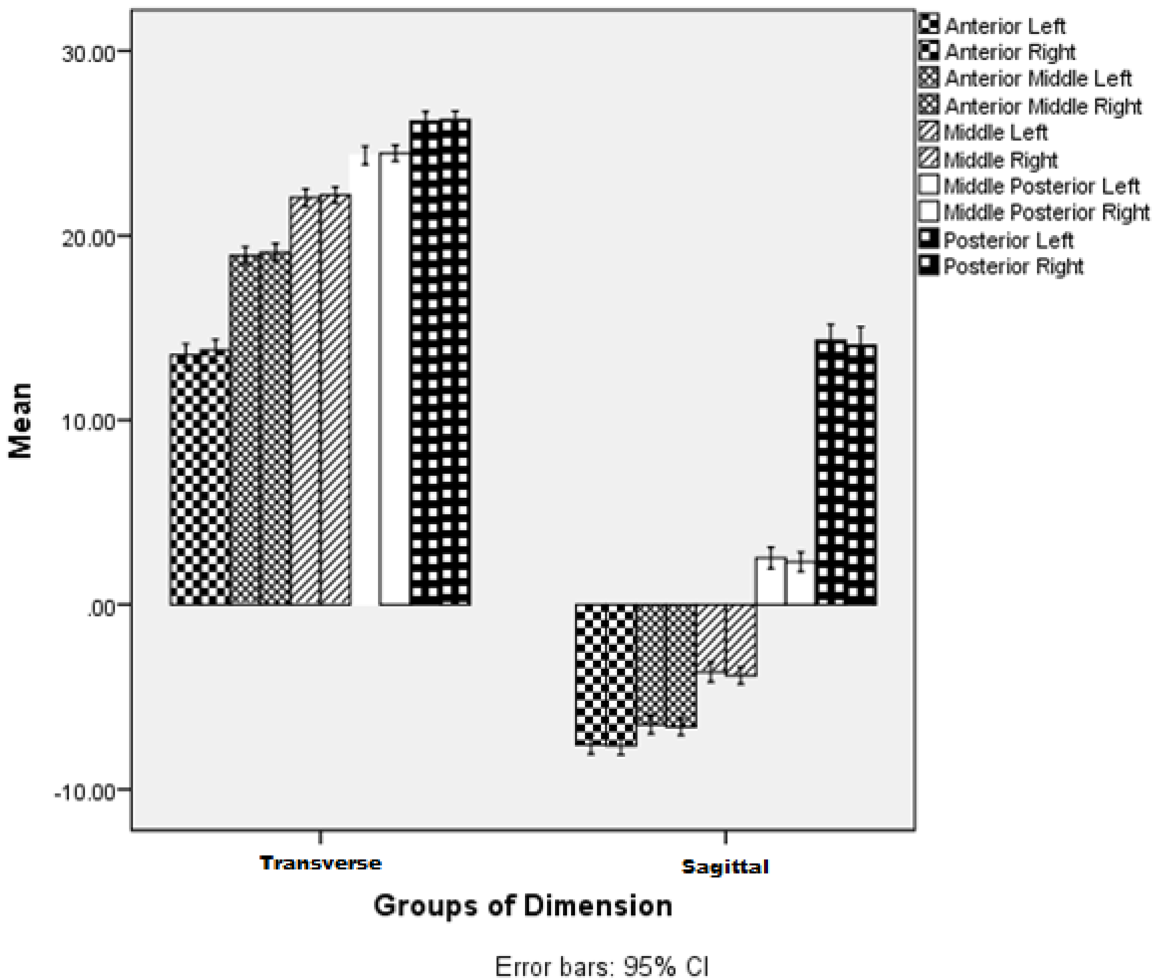

Figure 16. Clustered bar chart of arch form discrepancy present in cases treated with bilateral premolar extractions.

4.2.3 Comparison of Corresponding Transverse and Sagittal Measurements between the Unilateral and Bilateral Extraction Groups

The difference between the mean values of x obtained from averaging three points at each segment of the arch (transverse measurements) are reported in Table IX for the unilateral extraction group and in Table X for the bilateral extraction group. The difference between the mean values of y obtained from averaging three points at each segment of the arch (sagittal measurements) are reported in Table XI for the unilateral extraction group and in Table XII for the bilateral extraction group. These tables can be found in the appendix

Independent student t-tests were performed to compare mean differences in transverse and sagittal measurements between the unilateral and bilateral premolar extraction groups.

4.2.3.1 Transverse Measurements

According to Levene's test for equality of variance, the population variances are assumed to be equal for the first variable only (anterior). The null hypothesis of equal variances is rejected for the remaining four variables. Along these lines, two of the five segments of the arch in the transverse dimension show statistically significant mean differences between the two groups with p-values ranging from 0.013 to 0.033. These areas include the anterior and anterior-middle segments of the arch. The middle, middle-posterior and posterior areas of the arch show no statistically significant mean differences, p-value > 0.05. Based on this, the study rejects the null hypothesis that the effect of unilateral premolar extraction treatment on the dental arch form symmetry is not significantly different in comparison to bilateral premolar extractions in the transverse dimension. Table XIII summarizes the descriptive statistics and the test results. A clustered bar chart provides a visual representation of the arch form discrepancy in the transverse dimension between the two groups (Figure 17).

TABLE XIII. INDEPENDENT STUDENT T-TEST RESULTS FROM THE COMPARISON OF TRANSVERSE MEASUREMENTS BETWEEN THE UNILATERAL AND BILATERAL EXTRACTION GROUPS.

Experimental Groups		N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Test- Unilateral Extraction	13	1.1894	1.03197	.28622	.20422	1.62079	.013
	Control- Bilateral Extraction	20	.2769	.93687	.20949			
Anterior-Middle	Test- Unilateral Extraction	13	.8782	1.02483	.28424	.06545	1.33755	.033
	Control- Bilateral Extraction	20	.1767	.38530	.08616			
Middle	Test- Unilateral Extraction	13	.7618	1.13674	.31528	-.06727	1.32593	.073
	Control- Bilateral Extraction	20	.1325	.31195	.06975			
Middle-Posterior	Test- Unilateral Extraction	13	.6958	1.21877	.33803	-.15892	1.33729	.113
	Control- Bilateral Extraction	20	.1066	.35326	.07899			
Posterior	Test- Unilateral Extraction	13	.6517	1.27926	.35480	-.22535	1.35053	.148
	Control- Bilateral Extraction	20	.0891	.40860	.09137			

*p-values statistically significant at α ≤ 0.05.

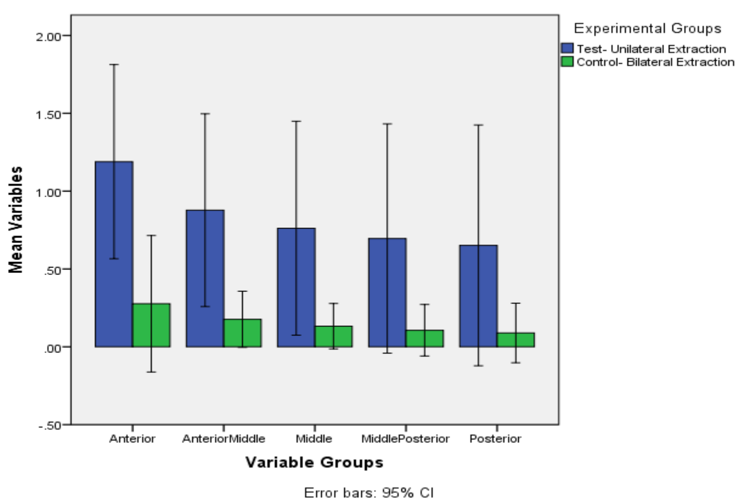

Figure 17. Clustered bar chart of the arch form discrepancy present in the transverse dimension between the experimental groups.

4.2.3.2 Para-Sagittal Measurements

According to Levene's test for equality of variance, the population variances are assumed to be equal for three variables (Anterior, Anterior-Middle and Middle). The null hypothesis of equal variances is rejected for the remaining two variables. Along these lines, two of the five segments of the arch in the sagittal dimension show statistically significant mean differences between the two groups with p-values ranging from 0.008 to 0.028. These areas include the middle and middle-posterior segments of the arch. The anterior, anterior-middle and posterior areas of the arch show no statistically significant mean differences, p-value > 0.05. Based on this, the study rejects the null hypothesis that the effect of unilateral premolar extraction treatment on the dental arch form symmetry is not significantly different in comparison to bilateral premolar extractions in the sagittal dimension. Table XIV summarizes the descriptive statistics and the test results. A clustered bar chart provides a visual representation of the arch form discrepancy present in the sagittal dimension between the two groups (Figure 18).

TABLE XIV. INDEPENDENT STUDENT T-TEST RESULTS FROM THE COMPARISON OF PARA-SAGITTAL MEASUREMENTS BETWEEN THE UNILATERAL AND BILATERAL EXTRACTION GROUPS.

	Experimental Groups	N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Anterior	Test- Unilateral Extraction	13	.1882	.30289	.08401	-.07077	.34041	.191
	Control- Bilateral Extraction	20	.0534	.26959	.06028			
Anterior-Middle	Test- Unilateral Extraction	13	.4854	.58448	.16211	-.04050	.76776	.076
	Control- Bilateral Extraction	20	.1218	.53757	.12020			
Middle	Test- Unilateral Extraction	13	.8936	.82733	.22946	.20149	1.21862	.008
	Control- Bilateral Extraction	20	.1835	.60581	.13546			
Middle-Posterior	Test- Unilateral Extraction	13	1.4763	1.77051	.49105	.15278	2.32994	.028
	Control- Bilateral Extraction	20	.2349	.53921	.12057			
Posterior	Test- Unilateral Extraction	13	2.2968	3.93526	1.09144	-.38741	4.43689	.093
	Control- Bilateral Extraction	20	.2721	1.08970	.24366			

*p-values statistically significant at α ≤ 0.05.

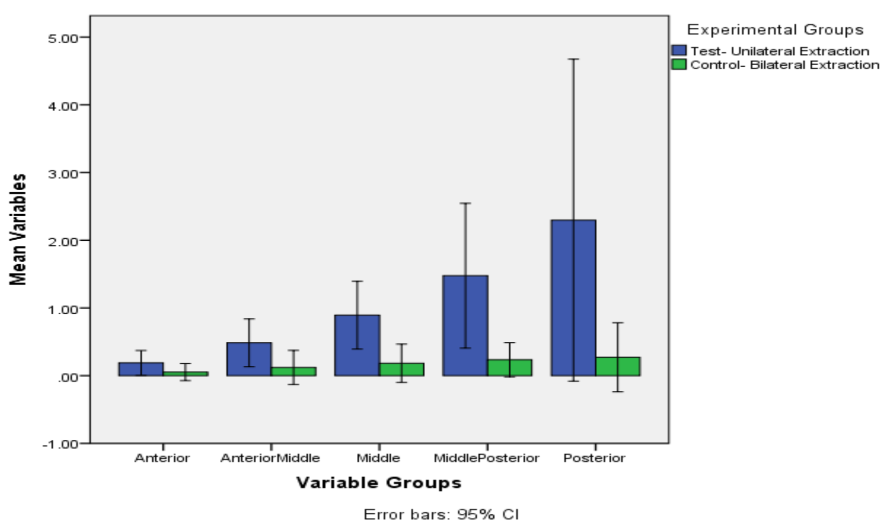

Figure 18. Clustered bar chart of the arch form discrepancy present in the sagittal dimension between the experimental groups.

4.3 Midline Deviation

The magnitude of maxillary midline deviation relative to the mid-sagittal plane within the bilateral and unilateral extraction groups are listed in Tables XV and XVI respectively. In the unilateral extraction group, FA_{x1} and FA_{x2} denote the absolute x-values of the digitized FA points of the maxillary central incisors on the non-extraction and extraction halves of the arch respectively. These tables can be found in the Appendix.

Measurements involving midline deviation showed to be normally distributed only for the unilateral extraction group according to the Shapiro-Wilk test of normality. The data for the control group did not show normal distribution. Non-parametric tests were performed (Mann-Whitney) and similar conclusions to those of parametric testing were drawn. As a result, all findings are reported from parametric tests.

On average, the midline was found to deviate from the constructed mid-sagittal plane by 1.2251 mm towards the extraction side in the testing group, and 0.386903 mm in the control group. Independent student t-test was performed to assess mean differences in maxillary midline deviation relative to the mid-sagittal plane between the unilateral and bilateral premolar extraction groups. Population variances were not assumed to be equal according to Levene's test for equality of variance. Along these lines, results showed statistically significant difference in midline deviation relative to the mid-sagittal plane between the two groups, with a p-value of 0.007. Based on this, the study rejects the null hypothesis that dental midline deviation relative to the mid-sagittal plane does not differ significantly between Class II subdivisions patients treated with unilateral and bilateral premolar extractions. Table XVII summarizes the descriptive statistics and test results. A clustered bar chart provides a visual representation of the midline deviation relative to the mid-sagittal plane in the two groups (figure 19).

TABLE XVII. INDEPENDENT STUDENT T-TEST RESULTS FROM THE COMPARISON OF MIDLINE DEVIATION BETWEEN THE UNILATERAL AND BILATERAL EXTRACTION GROUPS.

	Experimental Groups	N	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Sig. (2-tailed)*
						Lower	Upper	
Midline Deviation	Test- Unilateral Extraction	13	1.2251	.90870	.25203	.27219	1.40416	.007
	Control- Bilateral Extraction	20	.3869	.36294	.08116			

*p-values statistically significant at α ≤ 0.05.

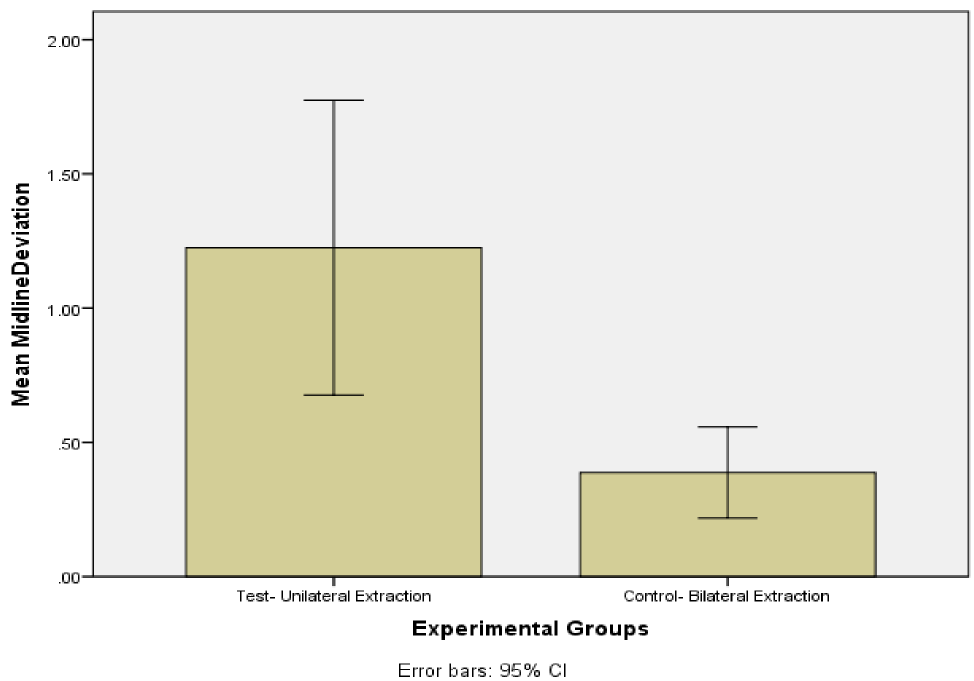

Figure 19. Bar chart of the midline deviation from the mid-sagittal plane in experimental groups.

4.4 <u>Superimpositions</u>

Arches from each group superimposed in Geomagic™ software on the constructed reference planes are displayed in Figure 20 and 21 respectively. The average arch generated from these superimpositions can also be seen. Measurements made in the transverse and sagittal dimensions to analyze arch form are reported in Table XVIII, and measurements of midline deviation relative to the mid-sagittal plane are reported in Table XIX.

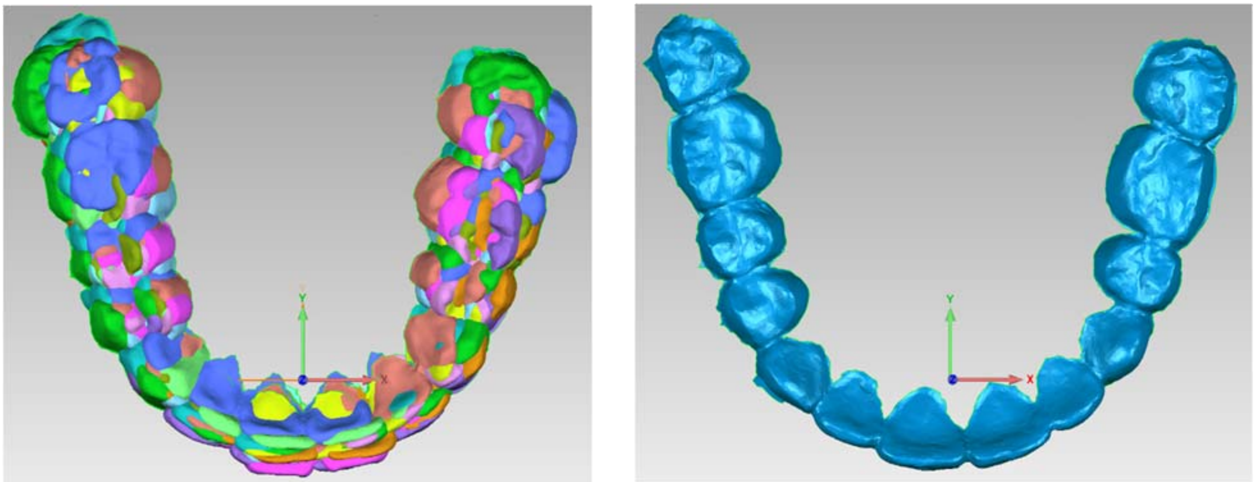

Figure 20. Unilateral extraction arches: A) superimposed on the reference planes, B) Constructed average arch.

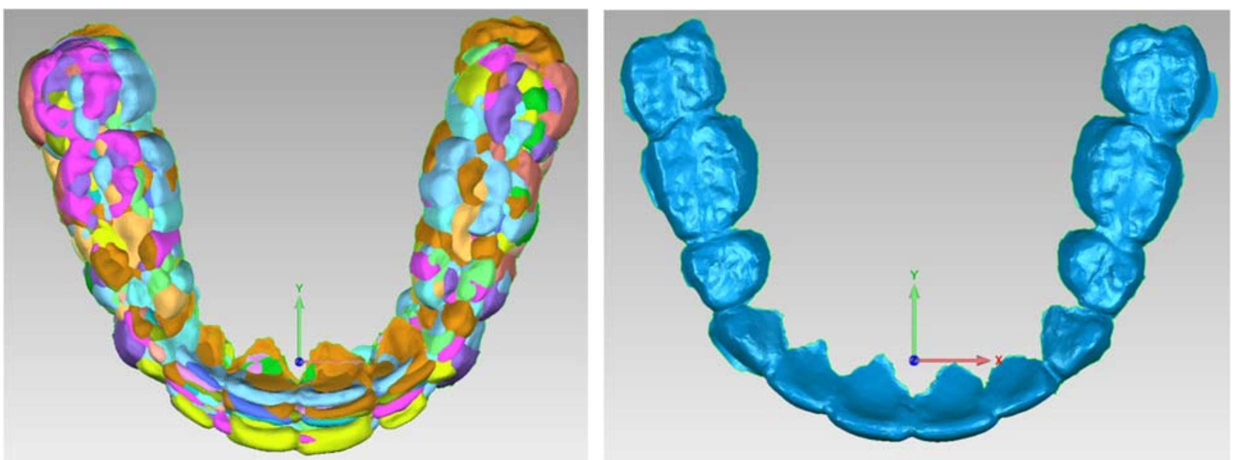

Figure 21. Bilateral extraction arches: A) Superimposed on the reference planes, B) Constructed average arch.

TABLE XVIII. ARCH FORM MEASUREMENTS OF SUPERIMPOSED AVERAGE ARCH OF EACH EXPERIMENTAL GROUP.

Experimental Group		ANTERIOR	ANTERIOR-MIDDLE	MIDDLE	MIDDLE-POSTERIOR	POSTERIOR
Transverse Measurements	Unilateral Premolar Ext	1.34943333	1.0208	0.9021	0.83513333	0.79066667
	Bilateral Premolar Ext	0.4527	0.27693333	0.19923333	0.1526	0.1206
Sagittal Measurements	Unilateral Premolar Ext	0.239	0.6041	1.0807	1.73255	2.62335
	Bilateral Premolar Ext	0.0967	0.2142	0.30445	0.3517	0.3404

TABLE XIX. MIDLINE DEVIATION OF SUPERIMPOSED AVERAGE ARCHES FOR EACH EXPERIMENTAL GROUP.

Experimental Group	FA_{x1}	FA_{x2}	Distance of midline to palatal raphe (mm)
Unilateral Premolar Extraction	2.987622	6.690776	1.851577
Bilateral Premolar Extraction	4.391336	5.205921	0.407293

The standard treatment summary forms of each patient in the unilateral premolar extraction group were thoroughly reviewed. Table XX presents a concise summary of the primary mechanisms employed for space closure in these cases.

TABLE XX. SPACE CLOSURE MECHANICS USED IN UNILATERAL PREMOLAR EXTRACTION SUBJECTS.

Treatment Mechanics	Number of Subjects
Class II/III elastics and powerchain	9
Class II/III elastics and powerchain in addition to molar anchorage (headgear/gable bend/TAD)	3
TAD to protract posterior teeth	1

5. DISCUSSION

5.1 <u>Choice of Methods</u>

In our investigation MATLAB™ software was designed to express the dental arch form as a fourth degree or quadratic polynomial expression. A fourth degree polynomial is an equation in which the highest exponent of a variable is four. Following the application of multiple different polynomial functions of various degrees during our study design phase, the fourth degree was selected to construct the best fitting curve seeing that it yielded the smoothest curve with no wave-like properties and most accurately represented the dental arch form. Literature also reports the quartic polynomial to be one of the best mathematical representations of the dental arch surpassing both the cubic spline and the beta function (AlHarbi et al., 2008). Although higher order polynomials to the 5^{th} or 6^{th} degrees may be more precise in fit and offer greater reduction in error, Lee et al. (2011) argues the arch form may become more inaccurate and irregular along the curve because of inherent asymmetries present in all arches. The aim is to define the overall arch form as opposed to expressing teeth irregularity. Quartic polynomials also have no general symmetry and for this reason are ideal for detecting any asymmetry if it is present.

Previous investigations commonly used conventional anatomic landmarks, such as the incisal edges of the anterior teeth and the cusp tips of premolars and molars, to describe the dental arch shape (BeGole and Lyew, 1998; Felton et al., 1987; Ferrario et al., 1993; McLaughlin and Bennett, 1999; Camporesi et al., 2006). In our study, dental arch shape was morphometrically analyzed on best fitting arch curves generated from landmarks taken on the vestibular surfaces of the dentition, specifically the facial axis (FA) points. These landmarks were selected because they correspond fairly well to the position of the brackets for straightwire therapy, thus giving a direct representation of clinical arch wire shape. (Andrews, 1989; Fujita et al., 2002; Camporesi et al., 2006).

Examinations of dentoalveolar asymmetry generally rely on dental models, with the majority focused on the maxillary arch only, employing the median raphe as an axis of symmetry (Mahmoud, 2008; Alavi et al., 1988). There is disagreement, however, on whether the median palatal raphe is an ideal reference plane in all patients (Lunstrom, 1961). Many raphes display curvature and are not just linear, which leads to difficulty in establishing a straight line across this structure (Burstone, 1998). There have been attempts to establish a skeletal midline using bilateral landmarks in the cranium, the orbits or other lateral points outside the skull. However, since there are differences in width between right and left sides in even the most symmetric profiles, bisecting the distance between two corresponding points can lead to an erroneous midline (Lunstrom, 1961; Burstone, 1998). The raphe still stands as the standard reference plane which researchers use to make transverse comparisons of the position of bilateral landmarks on dental models (Mahmoud, 2008).

5.2 Analysis and Clinical Implications of the Results

The concept of arch segmentation was developed in this study for the purposes of localizing measurement discrepancies to specific areas of the arch. Roughly, the anterior segment includes the anterior teeth, the middle segment includes the premolars, and the posterior segment includes the molars. Overlapping segments contain teeth that participate in more than one segment. The anterior segment of the dental arch is curved, the middle segment is more linear, and the posterior segment is essentially a straight line passing through the buccal cusps of the molars. The dental arch is shaped such that the incisors and canines cover a greater domain of measurement readings along the x-axis in comparison to the posterior teeth, and a shorter domain along the y-axis. It is imperative that we keep this in mind when speculating the location of the imbalance in our measurements and the specific areas of the arch they correspond to.

Results show that unilateral extraction of a premolar affects the dental arch form symmetry differently than extraction of premolars bilaterally. As suspected, distances of corresponding points between the right and left sides of the dental arch were approximately the same in both the transverse and sagittal dimensions for patients treated with bilateral premolar extractions, revealing a symmetrical pattern of dental arch forms. This was not the case in those treated with unilateral premolar extractions. Transversely, this group showed statistically significant differences in distance measurements of corresponding points in the following area segments: anterior, anterior-middle and middle. In the sagittal dimension, significant differences were found in all segments of the arch with the exception of the posterior segment. As illustrated earlier, considering the curvature of the dental arch, the majority of sagittal measurements made along the x-axis correspond to the incisors and canine areas, but the sector of transverse measurements taken along the y-axis that is covered by the incisors and canines is small. With this understanding, the stronger factors affecting dental arch asymmetry in this study are the incisors, canines, and to some measure the premolars. A comparison between the two groups showed statistically significant transverse differences in the anterior and anterior-middle segments, and sagittal disparities in the middle and middle-posterior segments. Overall, it appears that the discrepancies are more common in the anterior and middle areas of the arch.

Amongst the unilateral extraction group, the *positive* values of the mean x-value differences (refer to Table XIII) at each arch segment indicate the general trend of a narrower arch on the extraction side at all points along the y-axis. The greatest amount of transverse discrepancy was found to be existent in the anterior segment of the arch (1.1894 mm) with progressive decreases at each subsequent segment as we move posteriorly. The *positive* values of the mean y-value differences (refer to Table XIV) at each sagittal segment of the arch demonstrates the general trend of a more posteriorly displaced arch on the extraction side at all points along the x-axis. The least amount of discrepancy was found to be existent in the areas immediately adjacent to the mid-sagittal plane (0.1106333 mm), classified as the anterior segment, with progressive increases at each subsequent segment as we move laterally in both directions towards the posterior regions of the arch. Overall, the mean values and the range in transverse and sagittal measurement discrepancies between right and left sides of the arch was found to be less amongst the bilateral premolar extraction group than the unilateral extraction group as expected. Average arches constructed from superimpositions showed similar results.

Upon examination of the raw data, there were two subjects in which the non-extraction side was rather narrower transversely at most points along the y-axis. Evaluation of treatment mechanics shows both cases were treated exclusively with elastics and power chain to close the extraction space. One of these subjects also showed more posterior displacement of the non-extraction side at all points along the x-axis based on the sagittal measurements. A closer study of these cases revealed a pre-existing discrepancy in which the extraction side of the arch was wider and more anteriorly displaced pre-treatment relative to the non-extraction half of the arch. A lack of control in the amount of pre-existing discrepancy in the arch form between the right and left sides during subject selection resulted in these outliers.

Investigation of dental arch form characteristics such as symmetry is fundamental for identifying orthodontic problems and for establishing a normal functional occlusion post-treatment. The general trend shown by the results in this study is a larger amount of asymmetry in the unilateral extraction group with a constricted arch form on the side treated with the extraction. Aside from the posterior segment, essentially all segments of the arch showed some combination of displacement of the extraction side posteriorly and mesial towards the palatal raphe relative to the non-extraction side. It is expected that coordinated symmetrical arch wires should result in symmetrical arch forms, yet results indicate arch symmetry is not entirely achieved, a finding that matches the conclusions of a study done by Kusnoto et al. (2002). Our findings are justifiable considering the predominant mechanics utilized to close the unilateral extraction space in the testing group were elastics and power chains. Elastomeric chains have been reported in literature to be effective at condensing or constricting the arch (Andreason and Bishara, 1970; Weissheimer et al., 2013). Unilateral collapse of the arch form within a single jaw could potentially result in lack of coordination and poor intercuspation of dentition in opposing arches. Premature contacts or absence of an opposing occlusal stop are consequences of uncoordinated opposing arches. Asymmetry that is localized to the anterior area of the arch may result in asymmetric lateral overjet or an unaesthetic appearance of teeth upon smiling. Although statistically significant differences were found in this study, it is important to keep in mind the magnitude of the differences is small, within 1-2 mm, and can be considered clinically insignificant.

This study revealed correction of maxillary midline to be a challenging feat in the unilateral extraction group that often was not entirely accomplished. Subjects in this group consistently displayed deviation of the maxillary midline towards the extraction side of the arch in reference to the mid-sagittal plane. It is possible this esthetic compromise resulted from improper diagnosis and treatment of a well-positioned maxillary arch, matching it with its opposing asymmetric mandibular arch. On average, the midline was found to deviate from the constructed mid-sagittal plane by 1.2251 mm towards the extraction side in the testing group, and 0.386903 mm in the control group. Average arches constructed from superimpositions showed comparable results, displaying a deviation of the maxillary midline from the constructed mid-sagittal plane by 1.8516mm towards the extraction side in the testing group, and 0.4073mm in the control group. Whether these results are clinically significant in terms of esthetics depends on where the mid-palatal raphe and maxillary midline fall relative to the facial midline. Literature reports the limit of maxillary midline deviation found to be esthetically acceptable to patients is roughly 2 mm on either side of the facial midline (Joondeph, 2000). A deviation of 4mm was necessary before orthodontists rated it significantly less esthetic than others (Kokich et al., 1999). It has been suggested that an asymmetrical extraction pattern of three premolars as opposed to the conventional four premolar extraction pattern in Class II subdivisions can result in a greater improvement of the initial interdental midline deviation and a more desirable outcome (Janson, Dainesi, et al., 2003). Subdivision cases with mandibular midline deviation relative to the facial midline is a typical example in which three premolars can be extracted for treatment; two maxillary premolars and one mandibular premolar on the Class I side, allowing for midline correction accompanied with bilateral Class I canine relationships (Artun et al., 2013).

Asymmetric extraction pattern treatments, especially unilateral extractions are unconventional and infrequent. All things considered, perhaps this method of treatment is underrated and should be considered as a treatment option more often in cases where it is practical and beneficial to maintain a Class II molar relationship on one side of the arch. Although in most instances a Class I molar relation is the desired goal, maintaining existing molar relationships have been shown to have a better treatment outcome in Class II subdivisions (Janson, Dainesi, et al., 2003). One study shows better occlusal success rates in Class II malocclusions treated with two maxillary premolar extractions and maintaining Class II molar relations bilaterally in comparison to both upper and lower extractions (Janson, Brambilla, et al., 2004). Practitioners must avoid the temptation of practicing “cook book” recipes of similar types for treatment of cases and should rather customize mechanics to meet the individualized treatment needs for each patient. The combination of the teeth that are extracted in a dentally asymmetric case, whether it is unilateral or bilateral, should simplify intra and inter-arch mechanics for that specific patient, and allow for midline correction. In some cases, the benefits of unilateral extraction treatment reported in literature may outweigh any minor post-treatment discrepancies in arch form and midline that can result, although those are important elements of concern as well. Perhaps we can minimize these discrepancies by implementing mechanics to protract posterior dentition to close space on the unilateral extraction side rather than retraction of anterior teeth, preventing excess collapse of the arch or deviation of midline from ideal. Although perfect balance is desired, we must remember it is a natural phenomenon to have some amount of asymmetry present in the face and dentition, and perfect symmetry is only a theoretical concept that is rarely found (Melgaco and Araujo, 2012).

5.3 Discussion of Sources of Error (Strengths and Weaknesses)

The accuracy and availability of orthodontic records was of profound importance in a retrospective study such as this, especially during the subject selection phase. The quality of the post-treatment impressions or scans had an enormous influence in determining the accuracy of the results. Thus, instances where the labial surface of tooth structures or the mid-palatal raphe was not clearly defined due to a poor impression played an outsized role in the results. The selection of FA landmarks was challenging in cases where extreme gingival inflammation and overgrowth of gingival tissue onto tooth structure was present, resulting in errors in the construction of the best fitting XY plane and in the determination of the coordinate points used to construct the best fitting arch.

Small sample sizes also had a constraining effect by inhibiting categorization of subjects based on the degree of asymmetry present in the arches pre-treatment; by treatment mechanics used; or by the magnitude of space that required closure after extractions were performed. A number of subjects were treated with a combination of treatment mechanics for space closure making it problematic to categorize and draw appropriate conclusions about any specific treatment components.

Some of the strengths of the study were the inclusion of various practitioners, a variety of treatments, and a strong intra- and inter-examiner reliability correlation in the choice of methods. The study also worked with 3D digitized models that allowed for the rotation of dental structures in three dimensions, resulting in a superior sense of realism in structure visualization. The 3D model also facilitated a more precise selection of landmarks through the use of the shadows cast on the structures.

5.4 Future Studies

This study can be extended in order to look into whether asymmetric arch collapse during space closure in unilateral extraction treatment results in an asymmetric lateral overjet. This can be done by utilizing curves generated for both the upper and lower arches and measurements of the overjet at each facial axis point. The study can also determine if this leads to unaesthetic smiles. It would also be interesting to investigate whether unilateral extraction treatment results in more timely ideal cases compared to bilateral extraction treatments. Treatment time generally tends to increase when extractions are involved, and the number of extracted premolars has a direct correlation to treatment time (Cassidy et al., 2014), so the idea that unilateral extractions can reduce timelines is worth looking into. It would also be curious to look into the long-term stability of these types of cases, as the success of these treatment options is suspected, particularly when the finished occlusion is asymmetric and uncorrected minor skeletal asymmetries are still present post-treatment (Turpin, 2005). Additional studies can also examine if asymmetries corrected with extractions are more stable than cases where elastics and functional appliances were used (Cassidy et al., 2014). Researchers can also determine if Class II corrections are more likely to be stable when an ideal intercuspation is established.

6. CONCLUSION

The objective of this study was to evaluate post-treatment arch shapes and midlines for any imbalance and dissymmetry in occlusions treated with unilateral and bilateral premolar extractions

1. The distances of all corresponding points between the right and left sides of the dental arch in the transverse and sagittal dimension are approximately the same for those patients treated with bilateral premolar extractions, but not those treated with unilateral premolar extractions. The latter group shows statistically significant mean differences in the anterior, anterior-middle and middle segments of the arch in the transverse dimension, and all segments of the arch aside from the posterior segment in the sagittal dimension. The general trend is a narrower and more posteriorly displaced arch form on the extraction side.
2. The study rejects the null hypothesis that the effect of unilateral premolar extraction treatment on the dental arch form symmetry is not significantly different in comparison to bilateral premolar extractions. Two of the five segments of the arch, anterior and anterior-middle, show statistically significant mean differences between the two groups in the transverse dimension. Two of the five segments of the arch, middle and middle-posterior, show statistically significant mean differences between the two groups in the sagittal dimension.
3. A statistically significant difference in midline deviation relative to the mid-sagittal plane was observed between the two groups. Subjects in the unilateral extraction group consistently displayed deviation of the maxillary midline towards the extraction side of the arch.

There are undoubtedly several techniques to treat a case and achieve comparatively adequate results. It is important to carefully assess and evaluate the outcomes of our efforts for the sake of comparison of treatment methodologies and in the interest of understanding all available treatment options and the possible complexities and hurdles we can expect to face with each.

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APPENDIX
STUDY CERTIFICATION

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Exemption Granted

July 22, 2015

Ginu Dahiya, DDS
Orthodontics
801 S Paulina Street
M/C 841
Chicago, IL 60612
Phone: (312) 996-7505 / Fax: (312) 996-0873

RE: Research Protocol # 2015-0621
"Effects of Unilateral Premolar Extraction Treatment on the Dental Arch Form of Class II Subdivision Malocclusions"

Sponsors: None

Dear Dr. Dahiya:

Your Claim of Exemption was reviewed on July 20, 2015 and it was determined that your research meets the criteria for exemption. You may now begin your research.

Exemption Period:	**July 20, 2015 – July 20, 2018**
Performance Site:	UIC
Subject Population:	Pre-existing dental model casts, intra-oral photographs of teeth and summaries of diagnostic/treatment notes of retention cases at the UIC Orthodontics department. All records were initially collected for clinical purposes from January 1, 2000 through June 4, 2015.
Number of Subjects:	80

The specific exemption category under 45 CFR 46.101(b) is:
(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

HIPAA Waiver:
The Board determined that this research meets the regulatory requirements for waiver of authorization as permitted at 45CFR164.512(i)(1)(i)(A). Specifically, that the use or disclosure of protected health information (PHI) meets the waiver criteria under 45CFR164.512(i)(2)(ii); the research involves no more than a minimal risk to the privacy of the individuals; the research could

Phone: 312-996-1711 http://www.uic.edu/depts/ovcr/oprs/ Fax: 312-413-2929 not practicably be conducted without the waiver; and the research could not practicably be conducted without access to and use of the PHI.

Please note the Review History of this submission:

Receipt Date	Submission Type	Review Process	Review Date	Review Action
06/10/2015	Initial Review	Exempt	06/22/2015	Modifications Required
07/08/2015	Response to Modifications	Exempt	07/20/2015	Approved

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

2. Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

Please be sure to:

→ Use your research protocol number (2015-0621) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 355-2908. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne, B.S.
Assistant Director
Office for the Protection of Research Subjects

cc: Carlotta A. Evans, Orthodontics, M/C 841
David Crowe, Orthodontics, M/C 841
Privacy Office, Health Information Management Department, M/C 772

Tables

Comparison within Experimental Groups:

TABLE I. UNILATERAL EXTRACTION GROUP – TRANSVERSE MEASUREMENTS										
	ANTERIOR		ANTERIOR-MIDDLE		MIDDLE		MIDDLE-POSTERIOR		POSTERIOR	
Subject	Non-Ext	Ext	NonExt	Ext	NonExt	Ext	NonExt	Ext	NonExt	Ext
21	-14.7797	13.9243	-20.2923	19.21647	-23.4118	22.25887	-25.6941	24.4979	-27.5256	26.30087
22	-15.5358	12.24863	-19.7727	18.0112	-22.351	21.11263	-24.2884	23.33987	-25.8669	25.1094
23	-13.0906	14.27827	-19.4654	20.30863	-23.1707	23.8626	-25.8881	26.4895	-28.0671	28.6065
24	-14.2324	12.96973	-19.4173	18.70207	-22.4424	21.93177	-24.6779	24.28357	-26.4813	26.16467
25	-16.6051	15.33123	-21.1984	20.57697	-23.9221	23.5071	-25.9533	25.65113	-27.6023	27.37393
26	-15.5354	14.00127	-20.4021	18.62437	-23.1589	21.3032	-25.1837	23.28543	-26.8137	24.88757
27	-16.614	15.35053	-22.4194	20.13363	-25.5827	22.97347	-27.878	25.09203	-29.7137	26.8122
28	-14.4005	13.79957	-20.0036	20.59967	-23.3393	24.4288	-25.8215	27.19907	-27.8314	29.40363
29	-13.8459	13.2541	-19.2666	18.77737	-22.3842	21.9334	-24.6743	24.2454	-26.5153	26.1011
30	-14.1539	13.4657	-19.8065	19.56993	-23.1079	23.05177	-25.5448	25.59333	-27.5087	27.62773
31	-15.3772	13.8122	-20.3016	19.50227	-23.1942	22.65683	-25.3407	24.949	-27.0776	26.78193
32	-15.0285	13.65253	-20.0583	19.5847	-23.0211	22.86773	-25.2207	25.2468	-27.0005	27.1456
33	-16.9527	14.6015	-22.2287	19.60937	-25.2133	22.50797	-27.4041	24.6516	-29.1671	26.3836

TABLE II. UNILATERAL EXTRACTION GROUP - PARA-SAGITTAL MEASUREMENTS										
	ANTERIOR		ANTERIOR-MIDDLE		MIDDLE		MIDDLE-POSTERIOR		POSTERIOR	
Subject	Non-Ext	Ext	NonExt	Ext	NonExt	Ext	NonExt	Ext	NonExt	Ext
21	-7.6984	-7.68595	-6.74135	-6.557	-4.1031	-3.3744	1.88075	3.7393	13.6618	17.4484
22	-9.1239	-8.3004	-8.69865	-6.86895	-6.28035	-3.6649	0.1484	3.2032	13.47355	16.49545
23	-8.344	-8.59495	-6.62545	-7.2114	-2.83565	-3.758	4.448	3.1875	17.28065	15.67925
24	-8.4467	-8.14865	-7.42585	-6.7628	-4.40545	-3.45495	2.34765	3.46375	15.32705	16.4426
25	-9.9499	-9.5919	-9.4221	-8.6385	-6.7309	-5.6461	0.7456	1.93615	16.7788	17.8085
26	-7.9248	-7.9385	-7.3054	-7.04895	-5.1997	-3.9809	0.30125	3.56995	12.04255	18.8443
27	-8.1997	-8.49845	-7.46465	-7.72795	-5.52415	-4.71105	-0.7495	2.7758	9.3443	17.8123
28	-6.79225	-6.41545	-5.4545	-4.8499	-1.7452	-1.5718	6.03365	4.74035	20.2511	16.0791
29	-10.0035	-9.8948	-8.72625	-8.43875	-5.294	-4.74625	2.16	3.096	16.34245	17.8411
30	-7.60975	-7.41075	-6.35415	-5.95435	-3.0078	-2.56185	4.0654	4.31425	17.2091	16.92915
31	-8.4398	-8.0412	-7.63665	-6.763	-4.73415	-3.52095	2.362	3.70195	16.65955	17.83605
32	-1.17275	-0.77255	-0.29165	0.52305	2.6834	3.62695	9.6863	10.30985	23.4741	23.1655
33	-8.1317	-8.09695	-7.52845	-7.0664	-5.5085	-3.7046	-0.24085	4.34205	11.03525	20.35695

TABLE V. BILATERAL EXTRACTION GROUP - TRANSVERSE MEASUREMENTS										
	ANTERIOR		ANTERIOR-MIDDLE		MIDDLE		MIDDLE-POSTERIOR		POSTERIOR	
Subject	X1	X2	X1	X2	X1	X2	X1	X2	X1	X2
1	-13.5187	13.67214	-0.41083	-6.65133	-22.6771	22.65413	-25.2242	24.96927	-27.2534	26.8426
2	-13.6066	13.71494	0.124733	-6.83672	-23.4155	23.43473	-25.4776	25.5605	-27.1464	27.27117
3	-13.6384	13.98039	0.380933	-6.87338	-23.3187	23.4239	-25.4451	25.7166	-27.1684	27.54933
4	-13.142	13.21613	0.094667	-6.64935	-22.5134	22.46887	-24.5105	24.55	-26.1272	26.22183
5	-12.4375	13.08455	0.538467	-6.03547	-21.3173	21.7536	-23.4912	23.98877	-25.2417	25.78017
6	-11.9422	12.913	0.6073	-5.63748	-20.8363	21.4778	-22.8961	23.517	-24.5515	25.1588
7	-12.9617	13.46123	0.449667	-6.3664	-22.4274	22.75363	-24.4873	24.88807	-26.1522	26.60187
8	-13.5079	14.17649	-0.08937	-6.40625	-22.7627	23.1852	-25.5172	25.6356	-27.7112	27.62183
9	-13.1018	13.53338	0.044433	-6.34622	-21.753	22.0489	-24.4493	24.59723	-26.613	26.6574
10	-12.3044	12.96518	0.290433	-5.89442	-21.3845	21.80187	-23.4595	23.80027	-25.1244	25.4148
11	-13.807	13.85664	-0.07193	-6.8716	-22.9246	22.94147	-25.5613	25.52553	-27.6778	27.60583
12	-12.3997	12.70687	-0.3836	-6.0126	-21.4003	21.4378	-23.5016	23.28463	-25.1738	24.7902
13	-13.9062	13.7221	-0.37163	-7.08949	-23.1746	22.86277	-25.5966	25.24893	-27.5396	27.16793
14	-13.3217	13.39106	-0.5207	-6.59369	-22.1523	22.04927	-24.7267	24.37473	-26.7778	26.25713
15	-12.7192	12.62765	-0.183	-6.54823	-20.2413	19.90717	-22.8971	22.6495	-25.061	24.878
16	-12.5789	13.30119	0.677733	-6.11878	-20.9264	21.36633	-23.4538	24.03303	-25.4991	26.1768
17	-13.1773	12.93578	-0.483	-6.87006	-21.98	21.451	-24.0916	23.59037	-25.7917	25.30873
18	-12.8889	13.31001	0.273033	-6.30219	-22.1818	22.46143	-24.3324	24.60807	-26.0624	26.33547
19	-11.7617	12.61506	0.821633	-5.73517	-20.2654	20.77777	-22.2267	22.9251	-23.8149	24.63653
20	-13.6195	13.70045	-0.0063	-6.76833	-23.262	23.30647	-25.5129	25.5268	-27.3218	27.31553

TABLE VI. BILATERAL EXTRACTION GROUP - PARA-SAGITTAL MEASUREMENTS										
	ANTERIOR		ANTERIOR-MIDDLE		MIDDLE		MIDDLE-POSTERIOR		POSTERIOR	
Subject	X1	X2	X1	X2	X1	X2	X1	X2	X1	X2
1	-6.1848	-6.5795	-4.79765	-5.5746	-1.7866	-2.6001	4.18925	3.88245	15.111	16.0515
2	-9.0715	-8.9146	-8.47055	-8.1605	-6.02005	-5.69135	0.44445	0.5805	14.03245	13.6877
3	-6.79065	-6.4605	-6.1717	-5.5275	-3.7661	-3.11025	2.2523	2.4442	14.4826	13.5622
4	-7.92245	-7.69205	-7.2564	-6.79045	-4.56485	-4.0357	2.45085	2.77265	17.0893	16.8346
5	-9.9218	-9.84575	-8.87565	-8.78285	-5.9773	-6.0713	0.3859	-0.2147	12.5175	10.97435
6	-5.8233	-5.92125	-4.85205	-5.1355	-2.12015	-2.7211	4.11035	2.98475	16.3331	14.4003
7	-6.2061	-6.0468	-5.4531	-5.18225	-2.7689	-2.62865	3.90945	3.5388	17.5311	16.13085
8	-7.1095	-7.6417	-5.42155	-6.51995	-1.9988	-3.3195	4.4024	3.39995	15.6224	15.6752
9	-7.65245	-7.90415	-6.00485	-6.5331	-2.5701	-3.2336	3.72635	3.14975	14.45465	14.2678
10	-6.88265	-7.085	-5.95535	-6.4155	-3.35	-4.0392	2.7316	1.8586	14.89035	13.8952
11	-9.08005	-9.17285	-7.4496	-7.634	-3.73785	-3.9369	3.494	3.40125	16.33395	16.51255
12	-7.40375	-7.99485	-6.42145	-7.6054	-4.0685	-5.3765	1.3321	0.6365	12.26205	13.1832
13	-6.92175	-6.9547	-5.7485	-5.7728	-2.76975	-2.65945	3.56665	4.00975	15.5187	16.5647
14	-7.6489	-8.05145	-6.1519	-6.933	-3.0093	-3.789	3.02365	2.8423	13.793	15.02405
15	-9.10665	-8.95475	-7.58595	-7.2537	-4.3565	-3.89715	1.2715	1.77425	10.2877	10.71975
16	-8.11505	-8.00875	-6.7481	-6.58855	-3.6378	-3.63735	2.17205	1.67965	12.03555	10.5953
17	-7.56355	-7.45585	-6.69475	-6.40595	-4.0723	-3.51245	2.0458	3.018	14.18715	15.76445
18	-6.8943	-6.92045	-6.09225	-6.1773	-3.7319	-3.9335	1.7658	1.3569	12.6741	11.9343
19	-7.2228	-6.91535	-6.49385	-5.9442	-4.0701	-3.6806	1.5582	1.15525	12.5208	10.46305
20	-8.4191	-8.4884	-7.4655	-7.609	-4.6972	-4.87125	1.76485	1.62865	14.63995	14.63515

Comparison between Experimental Groups

TABLE IX. TRANSVERSE MEASUREMENTS – UNILATERAL EXTRACTION					
Subject	ANTERIOR	ANTERIOR-	MIDDLE	MIDDLE-	POSTERIOR
21	0.85536667	1.0758	1.15296667	1.19616667	1.22476667
22	3.28713333	1.76146667	1.23836667	0.9485	0.75753333
23	-1.18766667	-0.84326667	-0.69193333	-0.6014	-0.5394
24	1.26266667	0.7152	0.51063333	0.3943	0.31663333
25	1.27386667	0.6214	0.41496667	0.30216667	0.22833333
26	1.53413333	1.77776667	1.85566667	1.89823333	1.92616667
27	1.2635	2.28576667	2.60923333	2.78593333	2.90146667
28	0.6009	-0.59603333	-1.08946667	-1.37753333	-1.57226667
29	0.5918	0.48926667	0.45076667	0.42886667	0.4142
30	0.6882	0.2366	0.05613333	-0.0485	-0.11903333
31	1.565	0.79936667	0.53733333	0.39173333	0.29563333
32	1.37593333	0.47363333	0.15333333	-0.02613333	-0.14506667
33	2.3512	2.61933333	2.70533333	2.7525	2.78346667

TABLE X. TRANSVERSE MEASUREMENTS – BILATERAL EXTRACTION GROUP					
Subject	ANTERIOR	ANTERIOR-	MIDDLE	MIDDLE-	POSTERIOR
1	1.3905	0.37843333	-0.023	-0.2549	-0.41083333
2	-0.46346667	-0.09746667	0.0192	0.08293333	0.12473333
3	-1.1033	-0.19623333	0.1052	0.27153333	0.38093333
4	-0.67536667	-0.19796667	-0.04456667	0.03953333	0.09466667
5	0.03276667	0.32796667	0.4363	0.49756667	0.53846667
6	0.78746667	0.67873333	0.64153333	0.62093333	0.6073
7	-0.2233	0.19093333	0.32626667	0.40076667	0.44966667
8	2.09306667	0.9324	0.4225	0.1184	-0.08936667
9	1.02446667	0.53406667	0.2959	0.14793333	0.04443333
10	0.97323333	0.556	0.41736667	0.3408	0.29043333
11	0.30496667	0.10486667	0.01686667	-0.0358	-0.07193333
12	1.9335	0.50186667	0.0375	-0.21693333	-0.3836
13	-0.08356667	-0.2492	-0.31186667	-0.3477	-0.37163333
14	1.32733333	0.32016667	-0.10306667	-0.35193333	-0.5207
15	-0.6627	-0.45903333	-0.33416667	-0.24763333	-0.183
16	-0.21063333	0.22026667	0.43996667	0.57926667	0.67773333
17	-0.72226667	-0.57863333	-0.529	-0.50126667	-0.483
18	0.30776667	0.28673333	0.2796	0.27563333	0.27303333
19	-0.75543333	0.1801	0.51233333	0.69843333	0.82163333
20	0.26263333	0.09956667	0.04443333	0.01386667	-0.0063

TABLE XI. PARA-SAGITTAL MEASUREMENTS – UNILATERAL EXTRACTION

Subject	ANTERIOR	ANTERIOR-	MIDDLE	MIDDLE-	POSTERIOR
21	0.01245	0.18435	0.7287	1.85855	3.7866
22	0.8235	1.8297	2.61545	3.0548	3.0219
23	-0.25095	-0.58595	-0.92235	-1.2605	-1.6014
24	0.29805	0.66305	0.9505	1.1161	1.11555
25	0.358	0.7836	1.0848	1.19055	1.0297
26	-0.0137	0.25645	1.2188	3.2687	6.80175
27	-0.29875	-0.2633	0.8131	3.5253	8.468
28	0.3768	0.6046	0.1734	-1.2933	-4.172
29	0.10865	0.2875	0.54775	0.936	1.49865
30	0.199	0.3998	0.44595	0.24885	-0.27995
31	0.3986	0.87365	1.2132	1.33995	1.1765
32	0.4002	0.8147	0.94355	0.62355	-0.3086
33	0.03475	0.46205	1.8039	4.5829	9.3217

TABLE XII. PARA-SAGITTAL MEASUREMENTS – BILATERAL EXTRACTION GROUP

Subject	ANTERIOR	ANTERIOR-	MIDDLE	MIDDLE-	POSTERIOR
1	0.3947	0.77695	0.8135	0.3068	-0.9405
2	-0.1569	-0.31005	-0.3287	-0.13605	0.34475
3	-0.33015	-0.6442	-0.65585	-0.1919	0.9204
4	-0.2304	-0.46595	-0.52915	-0.3218	0.2547
5	-0.07605	-0.0928	0.094	0.6006	1.54315
6	0.09795	0.28345	0.60095	1.1256	1.9328
7	-0.1593	-0.27085	-0.14025	0.37065	1.40025
8	0.5322	1.0984	1.3207	1.00245	-0.0528
9	0.2517	0.52825	0.6635	0.5766	0.18685
10	0.20235	0.46015	0.6892	0.873	0.99515
11	0.0928	0.1844	0.19905	0.09275	-0.1786
12	0.5911	1.18395	1.308	0.6956	-0.92115
13	0.03295	0.0243	-0.1103	-0.4431	-1.046
14	0.40255	0.7811	0.7797	0.18135	-1.23105
15	-0.1519	-0.33225	-0.45935	-0.50275	-0.43205
16	-0.1063	-0.15955	-0.00045	0.4924	1.44025
17	-0.1077	-0.2888	-0.55985	-0.9722	-1.5773
18	0.02615	0.08505	0.2016	0.4089	0.7398
19	-0.30745	-0.54965	-0.3895	0.40295	2.05775
20	0.0693	0.1435	0.17405	0.1362	0.0048

Midline Measurements

TABLE XV. MAXILLARY MIDLINE DEVIATION IN SUBJECTS TREATED WITH UNILATERAL PREMOLAR EXTRACTION

SUBJECT	FA_{x1}	FA_{x2}	DISTANCE OF MIDLINE TO PALATAL RAPHE (mm)
21	2.631456	6.151457	1.7600005
22	3.721223	5.73593	1.0073535
23	2.129646	7.226096	2.548225
24	3.119696	5.108892	0.994598
25	4.161398	5.646647	0.7426245
26	3.97624	5.236071	0.6299155
27	2.464938	7.535585	2.5353235
28	4.572359	4.707899	0.06777
29	3.07072	6.559217	1.7442485
30	3.962548	5.26049	0.648971
31	3.979274	4.621132	0.320929
32	2.231759	7.436504	2.6023725
33	4.41891	5.066198	0.323644

TABLE XVI. MAXILLARY MIDLINE DEVIATION IN SUBJECTS TREATED WITH BILATERAL PREMOLAR EXTRACTIONS

SUBJECT	FA_{x1}	FA_{x2}	DISTANCE OF MIDLINE TO PALATAL RAPHE (mm)
1	4.295117	5.253759	0.479321
2	4.700539	4.881953	0.090707
3	4.359317	4.961922	0.3013025
4	5.150389	5.230193	0.039902
5	4.82299	5.064149	0.1205795
6	4.100819	5.138726	0.5189535
7	4.87971	5.546752	0.333521
8	4.903348	5.414726	0.255689
9	4.439261	4.867257	0.213998
10	4.813469	5.324835	0.255683
11	3.571505	6.214242	1.3213685
12	3.051551	5.737069	1.342759
13	5.003717	5.418605	0.207444
14	4.237671	5.045587	0.403958
15	4.08699	4.183372	0.048191
16	4.019957	4.83602	0.4080315
17	4.254576	5.693455	0.7194395
18	4.508547	4.975139	0.233296
19	4.346373	4.798469	0.226048
20	4.621223	5.05694	0.2178585

MATLAB™ Code

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function main(subjectFolder)
rootDir = 'C:\Users\Ginu\Documents\MATLAB\Project1\';
dataFile = [rootDir subjectFolder '\FinaltestPointCoordinates.txt'];

[TR,AP,VT,archFitResult,archFitGof,TRTest,bestFitAP,TRLevel1,TRLevel2,...

segCoordAPLevel1,segCoordAPLevel2,APdiff,APdiffNormalized,APdiffProportion,..
.
    avgAPDiff,avgAPdiffNormalized,TRDiff,avgTRDiff] = ...
    BestFitCurve(dataFile);
figure;plot(TR,AP,'o');axis equal;hold on;

h = plot(TRTest,bestFitAP,'r');axis equal;ylabel('Anterior-Posterior
(mm)');xlabel('Transverse (mm)')
savefig([rootDir subjectFolder '\regressionResults.fig']);
save([rootDir subjectFolder '\regressionResults.mat']);
clear all;close all;
```

archfit.m

```
function [fitresult, gof] = archFit(TR, AP,plotIt)
%CREATEFIT(TR,AP)
%  Create a fit.
%
%  Data for 'archFit' fit:
%      X Input : TR
%      Y Output: AP
%  Output:
%      fitresult : a fit object representing the fit.
%      gof : structure with goodness-of fit info.
%
%  See also FIT, CFIT, SFIT.

%  Auto-generated by MATLAB on 11-Dec-2014 19:19:02


%% Fit: 'archFit'.
[xData, yData] = prepareCurveData( TR, AP );

% Set up fittype and options.
ft = fittype( 'poly4' );

% Fit model to data.
[fitresult, gof] = fit( xData, yData, ft );

% Plot fit with data.
if plotIt
figure( 'Name', 'archFit' );
h = plot( fitresult, xData, yData );
legend( h, 'AP vs. TR', 'archFit', 'Location', 'NorthEast' );
% Label axes
xlabel TR
ylabel AP
grid on
end
```

BestFitCurve.m

```
function[TR,AP,VT,archFitResult,archFitGof,TRTest,bestFitAP,TRLevel1,TRLevel2
,segCoordAPLevel1,segCoordAPLevel2,APdiff,APdiffNormalized,APdiffProportion,a
vgAPDiff,avgAPdiffNormalized,TRDiff,avgTRDiff] = ...
    BestFitCurve(dataFile)

% Import Data
UpperCoordinates = importdata(dataFile);

% extract x, y, z coordinates
TR=UpperCoordinates.data(:,1);
AP=UpperCoordinates.data(:,2);
VT=UpperCoordinates.data(:,3);

% % Fit Occlusion Plane
% [OcclusionPlaneFitResult, OcclusionPlaneGof] = OcclusionPlaneFit(TR, AP,
VT,0);
% TRSlope = OcclusionPlaneFitResult.p10;
% APSlope = OcclusionPlaneFitResult.p01;

% Fit arch
[archFitResult, archFitGof] = archFit(TR, AP, 0);
TRTest = min(TR)-5:0.001:max(TR)+5;
bestFitAP = archFitResult(TRTest);

% Rules for deciding AP levels
APLevel = abs(max(AP));

% calculate distance in x
TRLessThan0_index = find(TRTest<0); % right side
TRGreaterThan0_index = find(TRTest>0); % left side
TRLevel1 =
interp1(bestFitAP(TRLessThan0_index),TRTest(TRLessThan0_index),APLevel);
TRLevel2 =
interp1(bestFitAP(TRGreaterThan0_index),TRTest(TRGreaterThan0_index),APLevel)
;

% calculate TR segments
% segmentSize = 2; % in mm

% find minimum TR level and divide TR in 10 segments
if abs(TRLevel1) > abs(TRLevel2)
    TRlength = abs(TRLevel2);
else
    TRlength = abs(TRLevel1);
end
segmentSize = TRlength/10;

segCoordTRLevel1 = 0:-segmentSize:TRLevel1;
segCoordTRLevel2 = 0:segmentSize:TRLevel2;

%compare number of segements on each side and remove the extra
if length(segCoordTRLevel1) > length(segCoordTRLevel2)
    segCoordTRLevel1 = segCoordTRLevel1(1:length(segCoordTRLevel2));
```

```
else
    segCoordTRLevel2 = segCoordTRLevel2(1:length(segCoordTRLevel1));
end
segCoordTRLevel1 = segCoordTRLevel1(2:end);
segCoordTRLevel2 = segCoordTRLevel2(2:end);

% calculatre AP for each segments
segCoordAPLevel1 =
interp1(TRTest(TRLessThan0_index),bestFitAP(TRLessThan0_index),segCoordTRLeve
l1);
segCoordAPLevel2 =
interp1(TRTest(TRGreaterThan0_index),bestFitAP(TRGreaterThan0_index),segCoord
TRLevel2);


APdiff = abs(segCoordAPLevel1-segCoordAPLevel2);
APdiffNormalized = APdiff/length(APdiff);
APdiffProportion = (APdiff/sum(APdiff))*100;
avgAPDiff = mean(APdiff);
avgAPdiffNormalized = mean(APdiffNormalized);


%% calculate TR difference
APLevel0 = interp1(TRTest,bestFitAP,0);
APLevelMax = max(AP);
segNumber = 15;
APLevelSegmented = linspace(APLevel0,APLevelMax,segNumber+1);
APLevelSegmented = APLevelSegmented(2:end);

TRLevel1 =
interp1(bestFitAP(TRLessThan0_index),TRTest(TRLessThan0_index),APLevelSegment
ed);
TRLevel2 =
interp1(bestFitAP(TRGreaterThan0_index),TRTest(TRGreaterThan0_index),APLevelS
egmented);

TRDiff = abs(abs(TRLevel1)-abs(TRLevel2));
avgTRDiff = mean(TRDiff);


% area1 =
polyarea([TRTest(TRLessThan0_index),0],[bestFitAP(TRLessThan0_index);min(best
FitAP(TRLessThan0_index))]');
% area2 =
polyarea([TRTest(TRGreaterThan0_index),0],[bestFitAP(TRGreaterThan0_index);mi
n(bestFitAP(TRGreaterThan0_index))]');
% areaDiff = abs(area1-area2);
```

OcclusionPlaneFit.m

```
function [fitresult, gof] = OcclusionPlaneFit(TR, AP, VT,plotIt)
%CREATEFIT(TR,AP,VT)
%  Create a fit.
%
%  Data for 'occlusionFit' fit:
%      X Input : TR
%      Y Input : AP
%      Z Output: VT
%  Output:
%      fitresult : a fit object representing the fit.
%      gof : structure with goodness-of fit info.
%
%  See also FIT, CFIT, SFIT.

%  Auto-generated by MATLAB on 11-Dec-2014 19:21:11


%% Fit: 'occlusionFit'.
[xData, yData, zData] = prepareSurfaceData( TR, AP, VT );

% Set up fittype and options.
ft = fittype( 'poly11' );

% Fit model to data.
[fitresult, gof] = fit( [xData, yData], zData, ft );

% Plot fit with data.
if plotIt
figure( 'Name', 'occlusionFit' );
h = plot( fitresult, [xData, yData], zData );
legend( h, 'occlusionFit', 'VT vs. TR, AP', 'Location', 'NorthEast' );
% Label axes
xlabel TR
ylabel AP
zlabel VT
grid on
view( 0.5, 24.0 );
end
```

VITA

NAME:	Ginu Devi Dahiya
EDUCATION:	Hon. B.Sc., Human Biology, Physiology and South Asian Studies, University of Toronto, Toronto, Ontario, 2009
	DMD, Dentistry, Case Western Reserve University School of Dental Medicine, Cleveland, Ohio, 2013
	Specialty Certificate, Orthodontics, University of Illinois at Chicago College of Dentistry, Chicago, Illinois, 2016 (anticipated)
	M.S., Oral Sciences, University of Illinois at Chicago, Chicago, Illinois, 2016 (anticipated)
PROFESSIONAL MEMBERSHIP:	American Association of Orthodontists Illinois Society of Orthodontists Chicago Dental Society American Dental Association