Orthodontic Treatment Planning Using Direct Visual Approximation of Arch Length Discrepancy and Cephalometric Analyses

Kathleen Rouse Vaught
Marquette University

ORTHODONTIC TREATMENT PLANNING USING DIRECT VISUAL APPROXIMATION OF ARCH LENGTH DISCREPANCY AND CEPHALOMETRIC ANALYSES

By

Kathleen Rouse Vaught, DMD

A Thesis submitted to the Graduate School, Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

Milwaukee, Wisconsin

August 2018

ABSTRACT

ORTHODONTIC TREATMENT PLANNING USING DIRECT VISUAL APPROXIMATION OF ARCH LENGTH DISCREPANCY AND CEPHALOMETRIC ANALYSES

Kathleen Rouse Vaught, DMD

Marquette University, 2018

Introduction: Space analysis and radiographic analyses are crucial elements in developing an orthodontic treatment plan. It is imperative that the orthodontist makes accurate measurements in order to come up with the most effective treatment options for each patient. Some practitioners refrain from direct measurements to determine arch length discrepancies and instead determine the amount of crowding by using direct visual approximation. In addition, more orthodontists do not routinely trace all cephalograms taken. If more and more orthodontists are using direct visual approximation to determine angular cephalometric measurements, it is important to assess the accuracy and reliability of these measurements. This study will focus on two critical aspects of the orthodontic diagnosis: space analysis and lateral cephalometric findings. As continuation of a 2017 pilot study, this research will:

1. Assess the accuracy of orthodontists' visual approximation
2. Assess how their visual approximation impacts the overall treatment plan.

Methods and Materials: One hundred and twenty seven orthodontic residents and clinicians were recruited in this project and completed a survey that included a section on demographics, 3 upper and lower occlusal photos of 3 orthodontic cases, and 3 cases of traced cephalograms. The survey was created using Google Forms and was distributed by the American Association of Orthodontists.

Results: An assessment of the effects on demographics on arch length assessment and cephalometric assessment were done using chi square tests and one way ANOVA. Results showed a trend to overestimate crowding. No clear associations between any demographics and results were found. Results showed a trend to overestimate crowding. Cephalometric responses did not have a high level of accuracy.

Conclusion: On average, orthodontists overestimated all arch length discrepancy measurements. Overall, orthodontists were not accurate at approximating cephalometric measurements, with a total of 54% choosing the correct measurement range. As both the amount of crowding and mandibular plane angle increased, more participants chose to treat the case with extractions. Transverse expansion was the most commonly used method to treat cases non-extraction.

ACKNOWLEDGMENTS

Kathleen Vaught, DMD

I would like to thank my director, Dr. Bhoomika Ahuja, for her guidance and support throughout the course of this study. I would also like to thank the members of my thesis committee. Dr. Dawei Liu and Dr. Nimeri, for helping me edit and improve my thesis. A special thank you to Dr. Stephen Saunders for all your help gathering and analyzing the data. Thank you to Dr. Maharaj Singh, for assisting with data analysis and interpretation. I would also like to thank all of the participants in this survey, without whom this thesis would not be possible. Finally, I would like to thank my parents, Bob and Kathy, for their lifelong support and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I
INTRODUCTION

Orthodontics is the dental specialty that focuses on the proper alignment and occlusion of the dentition. It involves the diagnosis, prevention, and treatment of dental and skeletal malformations. The first step in orthodontic diagnosis is the attainment of thorough patient records, followed by the development of a problem-oriented treatment plan. Records are an essential component to orthodontic treatment (Proffit, Fields and Sarver).

Orthodontic records are multi-faceted. A clinical exam is administered, during which the patient's primary concern, or chief complaint, is established. It is essential that the orthodontist identify and establish the primary reason each individual is seeking treatment. Additionally, intraoral photos, including buccal, frontal, and occlusal views, are captured. Extraoral photos include a frontal view both at smile and at rest, as well as a side profile view. Maxillary and mandibular alginate impressions, or intra-oral scans of the teeth, can be used to make physical or digital dental casts. Typically, two separate two-dimensional radiographs are obtained: a lateral cephalogram and a panoramic radiograph.

Utilizing all of the diagnostic information, the practitioner is then able to develop both an accurate diagnosis and treatment plan. The treatment plan must take in to account the occlusion, as well as the skeletal and facial features of the patient. The lateral cephalometric radiograph is the main tool for assessing skeletal features. It allows the practitioner to assess the relationship of the maxilla and the mandible both to each other and in relation to the cranial base. Intraoral photos, as well as diagnostic models, are used to evaluate both the occlusal relationships and the amount of dental crowding or spacing in each arch. After the proper analyses are performed, the diagnosis is completed and the final treatment plan is determined.

This study will focus on two critical aspects of the orthodontic diagnosis: space analysis and lateral cephalometric findings. Based on 2017 pilot study, this research will:

1. Assess the accuracy of orthodontists' visual approximation
2. Assess how their visual approximation impacts the overall treatment plan.

The objective is to determine practitioners' accuracy when performing space and cephalometric analyses using visual approximation, and how, if any, this impacts the treatment plan.

Chapter II
REVIEW OF THE LITERATURE

Cephalometrics

Lateral cephalometric radiographs were first introduced to the field of orthodontics by Broadbent in 1931 (Broadbent). Since that time, lateral cephalometric radiography has been routinely and widely used in orthodontic treatment planning. It involves the identification of hard tissue landmarks on the skull, usually followed by a tracing that relates the mandible and maxilla to both each other and the cranial base. Soft tissue landmarks are also identified and traced, providing information about the patients' facial profile (Proffit, Fields and Sarver).

The purpose of the cephalogram is to identify growth patterns, as well as the vertical and antereoposterior skeletal positions of the mandible and maxilla. Tooth positions and occlusal relationships can also be assessed (Proffit, Fields and Sarver). Additionally, cephalometrics provide a way to assess skeletal maturation via cervical maturation staging (Uysal et al.). Serial cephalograms may be taken at different time points and superimposed to determine patient remaining growth potential (Enlow). However, due to the well-established link between ionizing radiation and cancer, the ALARA principle should be followed by practitioners (S. C. White). It is paramount that patients are not routinely exposed to unnecessary radiation.

Cephalograms were initially hand traced and measured manually, which could be a time consuming process for the practitioner. Today, with the development of digital radiographs, most cephalograms are captured and analyzed digitally (Keim et al.). Once all landmarks have been accurately plotted, the computer software will calculate the measurements, along with the normal values and standard deviations, and determine the angulations. Many analyses exist, and it is possible for the practitioner to look at multiple analyses when treatment planning. For this study, the American Board of Orthodontists (ABO) analysis was used to trace and evaluate the cephalograms. Specifically, four separate measurements were analyzed for the purpose of this study. A brief description of these measurements is discussed below.

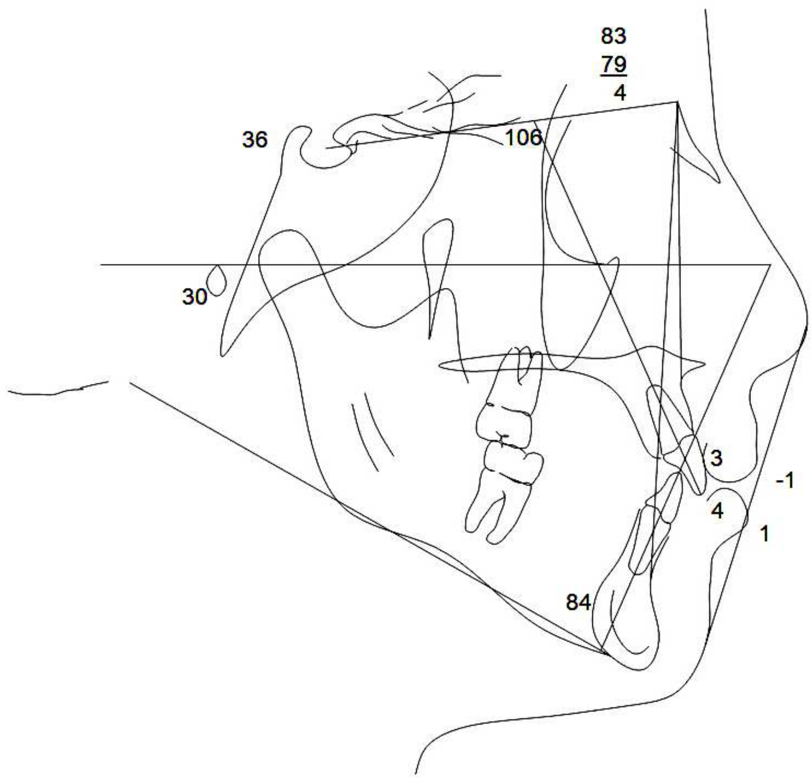


Figure 1. ABO 2012 cephalometric analysis. This figure is an example of the complete analysis utilized by the American Board of Orthodontics. Four of these measurements were utilized in this study: ANB, U1-SN, L1-MP, and MP-FH.

Table 1. ABO 2012 Cephalometric Measurements. Normal measurements, standard deviations, and deviations from normal from the American Board of Orthodontists cephalometric analysis.

	Norm	Std Dev	Dev Norm
ANB	1.6	1.5	2.9
U1-SN	102.9	5.5	3.3
L1-MP	95.0	7.0	-1.2
MP-FH	23.6	4.5	2.0

ANB

ANB is a commonly used measurement in cephalometrics. It describes the relationship of the maxilla to the mandible in relation to the cranial base. It is the measurement of the angle constructed from A point to Nasion to B point (Proffit, Fields and Sarver). Nasion is the junction between the nasal and frontal bones (Alexander Jacobson) A point, or subspinale, is the most posterior midline concavity between anterior nasal spine and the most inferior point on the alveolar bone overlaying the maxillary incisors (A. Jacobson; Alexander Jacobson). B point, also known as supramentale, is located on the mandible, at the most posterior midline concavity between pogonion and the mandibular alveolar process (Alexander Jacobson). Although the application of ANB has some limitations, it is commonly used in many analyses to relate the anteroposterior position of the maxilla and mandible (A. Jacobson).

U1-SN

U1 to SN is a measurement describing the axial inclination of the most labial maxillary central incisor in relation to the cranial base. SN is a line that passes through two separate landmarks: sella and nasion. As stated previously, nasion is the intersection of the frontal and nasal bones. Sella is a point located in the middle of the sella turcica, or pituitary fossa (Alexander Jacobson). SN is an easily located line that represents the anterior cranial base and is commonly used as a reference plane in cephalometric analyses (Steiner). U1 is a line passing through the maxillary incisory from the incisal edge to the root tip. The angle between U1 and SN demonstrates the relative proclination or inclination of the maxillary central incisors (Alexander Jacobson).

L1-MP

L1 to MP describes the axial inclination of the most labial mandibular incisor (L1) to the mandibular plane (MP). L1 is a line that runs through the central incisor from incisal edge to root tip (Alexander Jacobson). While MP is always meant to represent the lower border of the mandible, there are variations in the construction depending on the analyses used. The ABO analysis constructs MP as a line that runs from menton (Me) through constructed gonion (Figure 3). Menton is the most inferior point on the bony symphysis of the chin. Unlike menton, constructed gonion does not refer to a physical anatomical landmark. Instead, it is the midpoint of the angle between the mandibular and ramus planes (Figure 2).

MP-FH

MP-FH, also known as FMA, is an angle describing the vertical growth pattern of the mandible. Using Frankfort Horizontal plane as the reference, MP-FH relates the cant of the mandibular plane FH. Like SN, Frankfort Horizontal is a commonly used reference plane that is represented by a line passing from porion to orbitale (Alexander Jacobson).

Porion is the most superior point of the external auditory meatus, while orbitale is the most inferior point on the bony orbits (Alexander Jacobson). It is not uncommon for both right and left orbits to be visible in a single cephalogram. If this is the case, orbitale should be placed at the bisection of the two orbits (Alexander Jacobson).

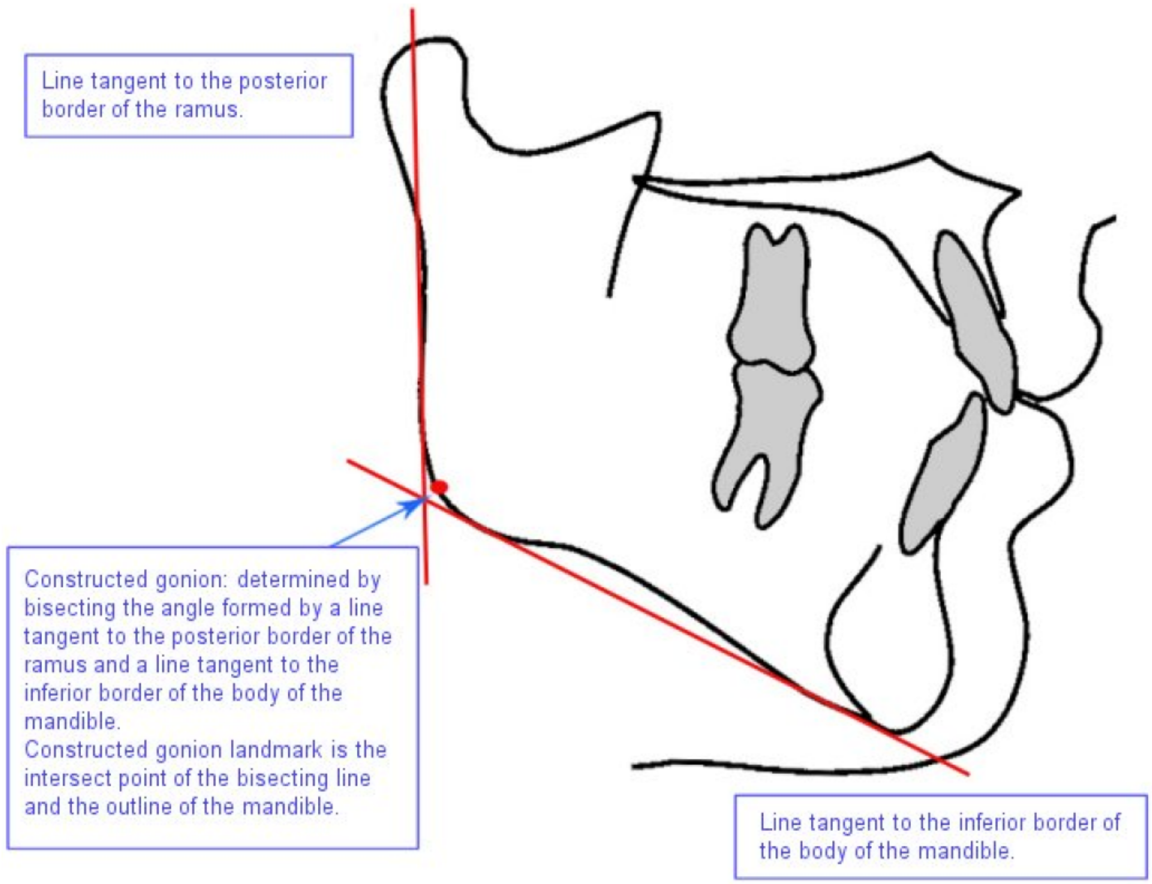


Figure 2: Constructed gonion. This point is not anatomical. Instead, it is formed using two separate lines: one tangent to the inferior border of the mandible, and the other tangent to the posterior border of the ramus. Constructed gonion is important in the determination of mandibular plane (Orthodontics).

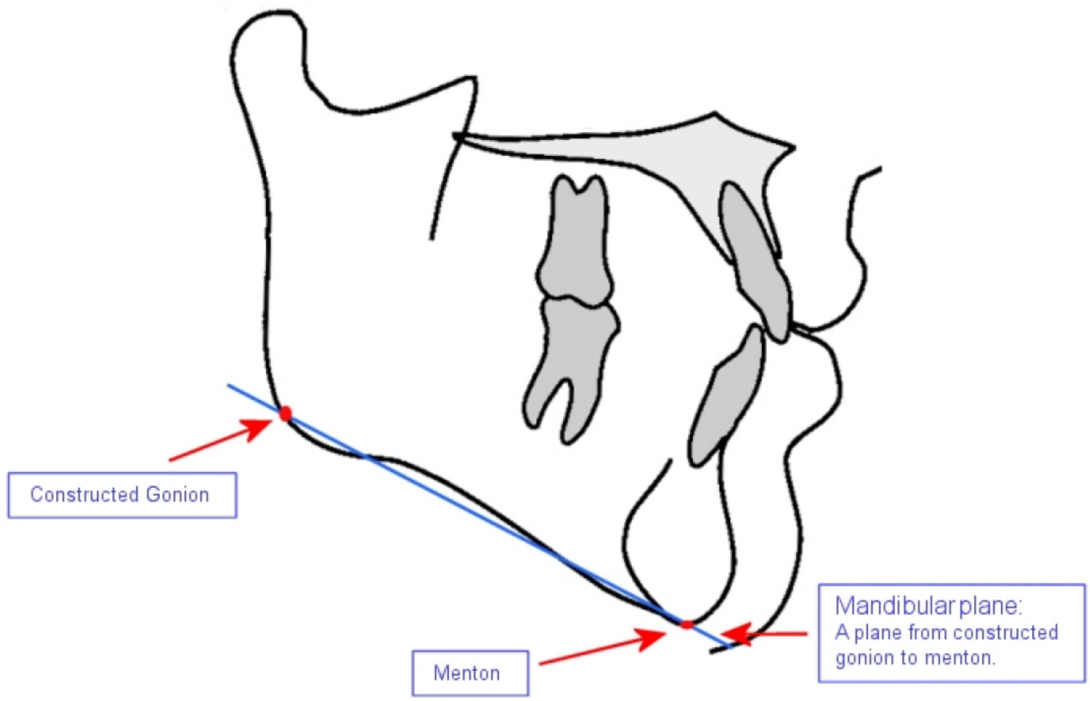


Figure 3: Mandibular Plane. The ABO 2012 cephalometric analysis creates the mandibular plane using two points: constructed gonion and menton (Orthodontics).

The Role of Cephalometrics in Treatment Planning

In 2015, it was reported that 97.3% of American orthodontists regularly took pretreatment lateral cephalometric radiographs (Keim et al.). Yet despite their routine use, there is a lack of scientific evidence that lateral cephalometric radiographs provide tangible value in orthodontic treatment planning (Durão et al.). Some studies have shown that the availability of lateral cephalograms does not contribute to a significant difference in diagnosis or treatment planning.

According to a 1991 study, diagnostic models alone provided enough information for treatment planning in up to 55% of all cases (Han et al.). More recently, Devereux et al found that the availability of a lateral cephalogram and its tracing did not make a significant difference in most treatment decisions (Devereux et al.). Interestingly, in one of the six cases shown to the orthodontists participating in the study, the decision to extract teeth did change significantly when practitioners were given to opportunity to view the lateral cephalogram. The results of this study further highlights the uncertainty surrounding the need for lateral cephalograms in treatment planning (Devereux et al.).

Perhaps adding to this uncertainty, some literature highlights the need for cephalometric radiographs only in certain types of malocclusion. The majority of orthodontists surveyed agreed that cephalometric radiographs are not needed in class I cases (plus or minus one quarter of a cusp) without obvious skeletal discrepancies (Manosudprasit et al.). Pae et al. concluded that lateral cephalograms did influence the treatment plan of practitioners, but only significantly in Class II, division 2 cases (Pae et al.). Another study concluded that lateral cephalograms were only needed for class II, div 1 patients (Silling et al.) .

Arch Length Discrepancy in Orthodontic Treatment Planning

Accurately determining the amount of crowding, or lack thereof, is a crucial element of orthodontic diagnosis and treatment planning. The two main components of dental crowding are the overall arch length of the jaw and the combined mesiodistal tooth widths (Howe, McNamara and O'Connor). Crowding of the teeth occurs when the sum of all mesiodistal tooth widths is greater than the amount of arch length available (Proffit, Fields and Sarver). Excessively large teeth, small alveolar bases, or a combination of these may result in dental crowding (Howe, McNamara and O'Connor). On the other hand, spacing occurs when the mesiodistal sum of the tooth widths is less than the amount of available arch length. Multiple space analyses have been developed to accurately determine the amount of true crowding in each arch (Al-Abdallah, Sandler and O'Brien; L. W. White). These analyses are typically performed on study models procured at the initial records appointment.

Han et al suggested that 88.2% of orthodontists regularly obtain study models for each patient (Han et al.). Traditionally, models made from plaster have been routinely used. With ever increasing technology, digital models are becoming more popular. Digital models have been shown to provide accurate and reproducible measurements, and space analyses between plaster and digital models are similar (Leifert et al.; Mullen et al.). These analyses, however, require the use of orthodontic study models, and can be time consuming for the practitioner. Some orthodontists may choose to forgo formal space analysis in lieu of more time efficient methods.

Direct visual approximation is the preferred method of space analysis among practitioners (Wallis et al.). Although this method may be preferred, it is not necessarily accurate and may impact the overall diagnosis and subsequent treatment plan. Several studies have demonstrated that when using direct visualization, practitioners tend to overestimate the amount of crowding (Naish et al.; Beazley; Johal and Battagel). Furthermore, when the true amount of crowding was revealed to orthodontists, they were more likely to change from an extraction to a non-extraction treatment plan (Naish et al.). This suggests that knowledge of the true amount of crowding may impact the treatment plan and influence the decision to extract teeth.

Although dental study models are traditionally used to calculate arch length discrepancy, practitioners may also use intraoral photos to visually approximate the amount of crowding. Measurements based on clinical photos are reliable when compared to dental cast measurements, with the exception of the mesiodistal widths of the upper first molars (Normando, da Silva and Mendes). A 2017 pilot study concluded that orthodontists have a tendency to overestimate the amount of crowding when visually approximating arch length discrepancy in occlusal photos (Wurm). However, there have been no published studies that assess the accuracy of direct visualization crowding estimates using clinical photographs. Taking this into account, this study does not account for the intermolar width or curve of Spee when determining the true amount of crowding.

Resolution of Dental Crowding

After the extent of dental crowding has been accurately diagnosed, it is the responsibility of the orthodontist to determine the best way to resolve any discrepancy. There are three main ways to resolve dental crowding: expansion, extraction, or interproximal reduction (Proffit, Fields and Sarver).

Proffit et al. have outlined a set of treatment guidelines to determine the most appropriate method for resolving crowding. They recommend that any discrepancy under 4 mm can be treated without extraction. Arch length discrepancies greater than 10 mm, however, will almost certainly require extractions to resolve the crowding. Discrepancies that fall in between these two parameters are borderline and may be treated by extraction or non-extraction(Proffit, Fields and Sarver). Ultimately it is the responsibility of the practitioner to take into account the dental, skeletal, and soft tissue components of each case. In these cases, it becomes increasingly important for the orthodontist to have accurate knowledge of the amount of true crowding. Practitioners have been shown to change their decision regarding extractions when informed that the true amount of crowding differs from their original visual approximation (Naish et al.).

The debate between extraction and non-extraction treatment dates back to the beginning of the orthodontic specialty. Edward Angle, known as the "father of modern orthodontics," advocated the non-extraction approach as early as 1907 (Proffit, Fields and Sarver). In the 1940s, Charles Tweed advocated the approach of treatment with the extraction of four bicuspids (Tweed). Today, extraction of permanent teeth remains a highly debated topic in orthodontics. Treatment is determined on a case-by-case basis, taking into account proper occlusion, function, facial and dental esthetics, and long term stability of the final results. While some practitioners feel that the advantages of removing permanent teeth never outweigh the disadvantages, others advocate for extractions as needed.

If extractions are not chosen as a treatment mechanism, dental crowding must be resolved in other ways. Transverse expansion, anterior advancement, or posterior distalization are methods used to increase the amount of available arch length (Proffit, Fields and Sarver). However, this can lead to expansion in the mandibular intercanine width. Changes in the mandibular intercanine width have been shown to lead to issues in long term stability and are more prone to relapse post-treatment (Bishara, Chadha and Potter). Other studies have shown that the patient's pretreatment arch form is the best predictor of future arch form stability (de la Cruz et al.).

Overall, one of the main goals of orthodontic treatment should be a functional occlusion that is resistant to relapse. Unfortunately, some post-treatment changes are inevitable, regardless of the treatment mechanics used (Little, Wallen and Riedel). In patients treated with extraction, relapse of overbite is more common than in patients treated without extractions (Francisconi et al.). Non-extraction treatment has been shown to lead to greater relapse of maxillary anterior crowding (Francisconi et al.). However, there is considerable individual variation, and it is the responsibility of the orthodontist to create an appropriate treatment plan.

Anchorage and Treatment Mechanics

In addition to managing arch length discrepancies, the orthodontist must determine the safest, most efficient way to achieve desired tooth movements. As previously mentioned, the orthodontist must establish a treatment plan after thorough review of patient records. It is essential to account for and execute specific tooth movements while minimizing unwanted, reciprocal forces. In orthodontics, this concept is known as anchorage. Anchorage is defined by Proffit as "resistance to unwanted tooth movement." (Proffit, Fields and Sarver). Anchorage can be thought of in two different planes of space: sagittal and vertical.

Controlling the vertical position of molars is important, especially in dolicocephalic patients with high mandibular plane angles (Schudy). Without proper control of the vertical dimension, orthodontic tooth movement can further rotate the mandible down and back, worsening the profile and further elongating the face (Kuhn; Isaacson et al.). Vertical anchorage can be provided using intraoral appliances, extraoral forces, or temporary anchorage devices.

Intraoral appliances include lower lingual holding arches (LLHAs) in the mandibular arch and transpalatal bars (TPAs) in the maxilla. In addition to preserving arch length, LLHAs are effective in controlling the vertical development of lower molars

(Villalobos, Sinha and Nanda). High-pull headgear is an extraoral appliance which has been shown to provide both a distalizing and intrusive force on maxillary molars (Firouz, Zernik and Nanda; Watson). It is often used for both vertical and saggital anchorage.

Finally, temporary anchorage devices, also known as TADs, are becoming increasingly popular in modern orthodontics. In cases with high mandibular plane angles and extruded posterior teeth, TADs can be used to intrude teeth and improve the vertical dimension (Kravitz et al.).

Regardless of what method is used for anchorage, it is crucial that the orthodontist decides on the anchorage needs for each patient and incorporates this decision into the treatment plan. When planned correctly, this will allow more efficient tooth movement and faster treatment times. Utilizing the lateral cephalometric radiograph, the orthodontist can evaluate the saggital and vertical skeletal dimensions of each patient. He or she can subsequently determine the type of anchorage needed in each treatment plan.

Study Aims

The purpose of this study will be to expand on previous research looking at the accuracy of direct visual approximation of cephalometric measurements and arch length discrepancy. Orthodontists and current orthodontic residents will be asked to visually estimate arch length discrepancy and cephalometric measurements, using occlusal photos and untraced lateral cephalometric radiographs, respectively. This study aims to evaluate the accuracy of these visual estimations, and to determine if practitioners with more experience are more accurate. Furthermore, the study will investigate how these measurements influence practitioners' treatment plans, if at all.

Chapter III
MATERIALS AND METHODS

The protocol for this study was approved by the institutional review board, number HR-1801022209, of Marquette University.

Materials

Google Forms™ (Google LLC) was utilized to create a digital questionnaire for respondents. Dolphin Imaging software was used for capturing and uploading both digital photos and lateral cephalograms. The ABO 2012 analysis within Dolphin Imaging was used for cephalometric analysis. Maxillary and mandibular alginate impressions were used to create dental models. The impressions were poured up in plaster and the resulting models were scanned with MotionView Ortho Insight 3D® scanner. Emodel® (GeoDigm Corporation) software was used to obtain model measurements.

Survey

A 2017 questionnaire was used as the basis for this study. The original questionnaire was modified to include four sections. The same questionnaire was given to all participants. The initial section of the survey outlined the purpose of the study, as well instructions and a general overview of the nature of the survey.

The second section consisted of ten questions regarding information on participant demographics and typical diagnostic practices.

The third section of the questionnaire consisted of three sets of intraoral photos. Each set of photos contained one maxillary occlusal photo and one mandibular occlusal photo, both in color. Participants were asked the visually approximate the amount of arch length discrepancy per arch in millimeters, rounding to the nearest 10^{th} of a millimeter. Participants were instructed not to take in to account the curve of Spee or the curve of Wilson in their estimations. Additionally, participants were instructed not to allow the inclination of the incisors contribute to their estimation. Based on their estimations, participants were then asked about treatment options, including extraction versus non-extraction.

The fourth section of the survey included three different cephalometric radiographs. Participants were instructed to estimate the following measurements: ANB, U1-SN, L1-MP, and mandibular plane to FH/FMA. For each of these measurements, participants were asked to pick from a range of measurements. Five equal ranges were provided for each category. Again, no tools were allowed. Based on their estimated measurements, participants were then asked a series of questions regarding both overall treatment plans and the need for vertical control.

Cephalogram and Model Analyses

Lateral cephalograms were taken using the Orthoceph OC200D® machine. Dolphin Imaging software was used for uploading intraoral photos and lateral cephalograms. Dolphin Imaging software was again used for cephalometric tracing and analysis of three separate subjects. The ABO 2012 analysis was used to determine the measurements. Maxillary and mandibular alginate impressions were taken and poured in white stone. These models were then scanned using Motionview Ortho Insight 3D® scanner.

Computer analysis was used to determine true measurements. All tooth landmarks were initially placed by the principal investigator, then checked and adjusted as needed. A caternary arch form from the mesial of first molar to first molar was superimposed over the patient's original arch form. The sum of the mesiodistal tooth widths was calculated and subtracted from the total arch length.

Lateral cephalometric radiographs were digitally traced using the Dolphin Imaging software. Landmarks were determined by the ABO 2012 analysis and manually located. Each cephalometric radiograph was traced three separate times, and the average for each value was calculated and utilized. All angular measurements were calculated using the ABO 2012 analysis.

Subjects

One hundred and twenty seven subjects participated in this survey. Subjects were comprised of orthodontic residents and orthodontists with various years of experience. The subjects included residents, faculty, and staff at Marquette University, all of whom were reached via email by the primary investigator. All other subjects were reached through the American Association of Orthodontists. Age of subjects ranged from residents in their late 20s to retired practitioners in their 80s. All subjects completed the survey voluntarily and had no requirement or incentive to do so. Subjects were given the option to opt out of the study at any time during the course of the survey.

Statistical Analyses

Statistical analysis was performed using one-way ANOVA to correlate the accuracy of crowding measurements with years of experience. Chi square tests were used for cephalometric comparisons. P-value <0.05 was considered to indicate significant difference. After initial analysis, data was combined to create three groups with different levels of experience. Low cell counts in the original group of "6-10 years" created artificial values, potentially undermining any statistical analyses. Therefore, this group was combined with those participants with "1-5 years" of experience, to create a new cohort with "6-10 years" of experience. One-way ANOVA analysis was performed to compare the participants' accuracy for each cephalometric value and arch length discrepancy to level of expertise.

All statistical analyses were performed by Dr. Stephen Saunders, the Director of Clinical Training of the Doctoral Program of Clinical Psychology at Marquette University, and Dr. Maharaj Singh, faculty member in the Department of Mathematics, Statistics, and Computer Science at Marquette University.

Chapter IV
RESULTS

Descriptive Statistics

One hundred and twenty seven subjects were recruited. **Table 2** shows frequency based on gender and frequency based on current level of expertise. 77.2% of those surveyed were male, and 75.6% had more than ten years of clinical orthodontic experience.

When asked about radiographic evaluation, most participants report that they "almost always" check cephalometric tracings when making an orthodontic diagnosis (**Table 3**). When determining arch length discrepancy, visual approximation was by far the most commonly reported method of space analysis. Only 39.4% reported using manual measurement and 20.5% utilizing a computer estimate when calculating arch length discrepancy (**Table 4**). Dental casts and clinical photos were the most commonly used by practitioners when deciding to treat a case with extraction, but a majority also utilized panoramic and cephalometric radiographs **(Table 4)**.

Orthodontists were also asked about specific techniques and appliances utilized in daily practice. Plaster dental casts were the most commonly used in this group of participants, followed by digital models. Only 7.1% of respondents said they do not routinely use dental casts in their daily practice **(Table 4)**. This cohort more commonly used traditional fixed appliances and clear aligners than lingual appliances **(Table 5)**.

The demographics of the survey also included a section to gauge orthodontists' beliefs about certain clinical practices. When surveyed, 73.2% of participants stated that they believe space analysis is "very important" in making the orthodontic diagnosis.

24.4% consider it to be “somewhat important,” and only 2.4% of participants believe that it is “not important” in making the orthodontic diagnosis. Participants also had different opinions about the most important factor when considering extraction treatment. Almost half of orthodontists questioned (49.6%) considered dental crowding the most important factor when considering extraction. This was followed closely by 45.7% of participants, who believe facial profile as the most important factor. The remaining 4.7% considered skeletal pattern most important **(Table 5)**.

Table 2. Descriptive Statistics. Frequencies describing gender and years of experience for all participants (N = 127)

Descriptor	**N (%)**
Gender	
Female	29(22.8)
Male	98 (77.2)
Years of Experience	164 (5.6)
Resident	15 (11.8)
1-5 years	10(7.9)
6-10 years	6 (4.7)
Greater than 10 years	96 (75.6)

Table 3. Checking Cephalometric Measurements. Frequency of checking cephalometric measurements when making an orthodontic diagnosis

Frequency	**N (%)**
Rarely	8 (6.3)
Only if unsure	25 (19.7)
Almost always	94 (74.0)

Table 4. Methods of Space Analysis and Type of Dental Cast Most Commonly Used.

	N (%)
Methods of Space Analysis	
Visual Approximation	102 (80.3)
Manual Measurement	50 (39.4)
Computer Estimate	26 (20.5)
Type of Cast Most Commonly Used	
Plaster	76 (59.8)
Digital	42 (33.1)
Don’t Routinely Use	9 (7.1)

Table 5. Physical Tests and Important Factors in Decision to Extract

	N (%)
Physical Tests for Extraction	
Dental Casts	122 (96.1)
Clinical Photos	117 (92.1)
Panoramic X-rays	104 (81.9)
Cephalometric x-rays	119 (93.7)
Most Important Factor in Extraction	
Dental Crowding	63 (49.6)
Facial Profile	58 (45.7)
Skeletal Pattern	6 (4.7)

Table 6. Practice trends by frequency and level of expertise.

	Resident		1-5 years		6-10 years		>10 years	
	N	%	N	%	N	%	N	%
Appliances								
Traditional Fixed	8	53.3	7	70	3	50	56	58.3
Clear Aligners	8	53.3	7	70	3	50	50	52.1
Lingual Fixed Appliances	0	0	0	0	1	26.7	17	17.7
Space Analysis								
Visual Approximation	12	80	9	90	6	100	75	78.1
Manual Measurement	8	53.3	6	60	2	33.3	34	35.4
Computer Estimate	7	46.7	3	30	1	16.7	15	15.6
Dental Casts								
Plaster Models	12	80	6	60	2	33.3	56	58.3
Digital models	3	20	4	40	4	66.7	31	32.3
Don't Routinely Use	0	0	0	0	0	0	9	9.4

Cephalometric Accuracy Ratings Associated with Expertise

The accuracy rate for each cephalometric measurement can be seen in **Table 7**. The accuracy rates range from 38% to 67%. **Tables 7, 8, and 9** detail the number of correct responses within each age range.

First, we compared participants' level of experience with accuracy for each individual cephalometric measurement. Chi square analysis was performed to compare participants' level of expertise to their accuracy. P-values were >0.05 in thirteen of the sixteen cephalometric measurements. Overall, candidates' current level of expertise did not impact accuracy. There were only four measurements found to have significant differences based on level of experience. In case 4, participants with more than ten years of experience were more likely to correctly approximate the mandibular plane angle. Similarly, in case 6, the mandibular plane angle was more correctly determined by those with more experience than those without. In cases 5 and 6, those with more experience were less likely to correctly approximate the ANB angle than those with less experience.

Finally, we analyzed the number of accurate responses for each cephalometric measurement across all three cases. The results are shown in **Table 11**. When visually estimating U1-SN, L1-MP, and FMA, there is no difference between level of expertise and accuracy **(Fig 5, 6,7)**. When visually estimating ANB, however, there was a significant difference between groups with different levels of expertise **(Fig 4)**. When visually approximating ANB, the resident participants were more accurate overall ($p=0.0143$) than those with 1-5 years of experience and those with more than ten years of experience.

Table 7. Percentage of Correct Cephalometric Measurements.

Case 4	**Correct (N)**	**Percentage**
ANB	78	61
U1-SN	84	66
L1-MP	77	60
FMA	82	64
Case 5	**Correct (N)**	**Percentage**
ANB	65	51
U1-SN	49	38
L1-MP	64	50
FMA	68	53
Case 6	**Correct (N)**	**Percentage**
ANB	86	67
U1-SN	51	40
L1-MP	57	44
FMA	65	51

Table 8. Case 4 responses. Cephalometric response accuracy compared to level of experience. P<0.05 indicates a significant difference.

	Resident	**1-5 years**	**6-10 years**	**>10 years**	**Total**	**x2**
ANB						0.289
Underestimate	3	2	4	35	44	
Correct	12	8	2	56	78	
Overestimate	0	0	0	5	5	
U1-SN						
Underestimate	1	1	1	65	19	0.402
Correct	10	7	2	15	84	
Overestimate	4	2	3	96	24	
L1-MP						
Underestimate	0	0	1	7	8	0.638
Correct	10	7	2	58	77	
Overestimate	5	3	3	31	42	
FMA						
Underestimate	0	1	2	24	27	0.016
Correct	15	9	4	54	82	
Overestimate	0	0	0	18	18	

Table 9. Case 5 responses. Cephalometric response accuracy compared to level of experience. P<0.05 indicates a significant difference.

	Resident	1-5 years	6-10 years	>10 years	Total	x2
ANB						0.127
Underestimate	2	2	2	20	26	
Correct	12	7	3	43	65	
Overestimate	1	1	1	33	36	
U1-SN						
Underestimate	1	1	1	19	22	0.582
Correct	5	5	1	38	49	
Overestimate	9	4	4	39	56	
L1-MP						
Underestimate	1	1	1	19	22	0.506
Correct	11	6	2	45	64	
Overestimate	3	3	3	32	41	
FMA						
Underestimate	12	4	4	39	59	0.026
Correct	3	6	2	57	68	
Overestimate						

Table 10. Case 6 responses. Cephalometric response accuracy compared to level of experience. P<0.05 indicates a significant difference.

	Resident	**1-5 years**	**6-10 years**	**>10 years**	**Total**	**x2**
ANB						0.018
Underestimate	2	0	4	30	36	
Correct	12	9	1	64	86	
Overestimate	1	1	1	2	5	
U1-SN						
Underestimate	8	7	2	45	62	0.583
Correct	7	2	3	39	51	
Overestimate	0	1	1	12	14	
L1-MP						
Underestimate	6	4	4	44	58	0.18
Correct	8	6	0	43	57	
Overestimate	1	0	2	9	12	
FMA						
Underestimate						
Correct	7	3	3	49	62	0.651
Overestimate	8	7	3	47	65	

Table 11. Cephalometric Estimation Accuracy. Average accuracy for each cephalometric variable compared to experience level. Measurements shown are given on a scale from 0 to 3.

Experience Level	N	Variable	Mean	Std Dev
Resident	**15**	**ANB**	2.40	0.74
		U1_SN	1.47	0.83
		LI_MP	1.93	0.88
		FMA	1.67	0.72
1-10 Years	**16**	**ANB**	1.88	1.09
		U1_SN	1.25	0.77
		LI_MP	1.44	1.03
		FMA	1.69	0.70
>10	**96**	**ANB**	1.70	0.84
		U1_SN	1.48	0.89
		LI_MP	1.52	0.86
		FMA	1.67	0.76

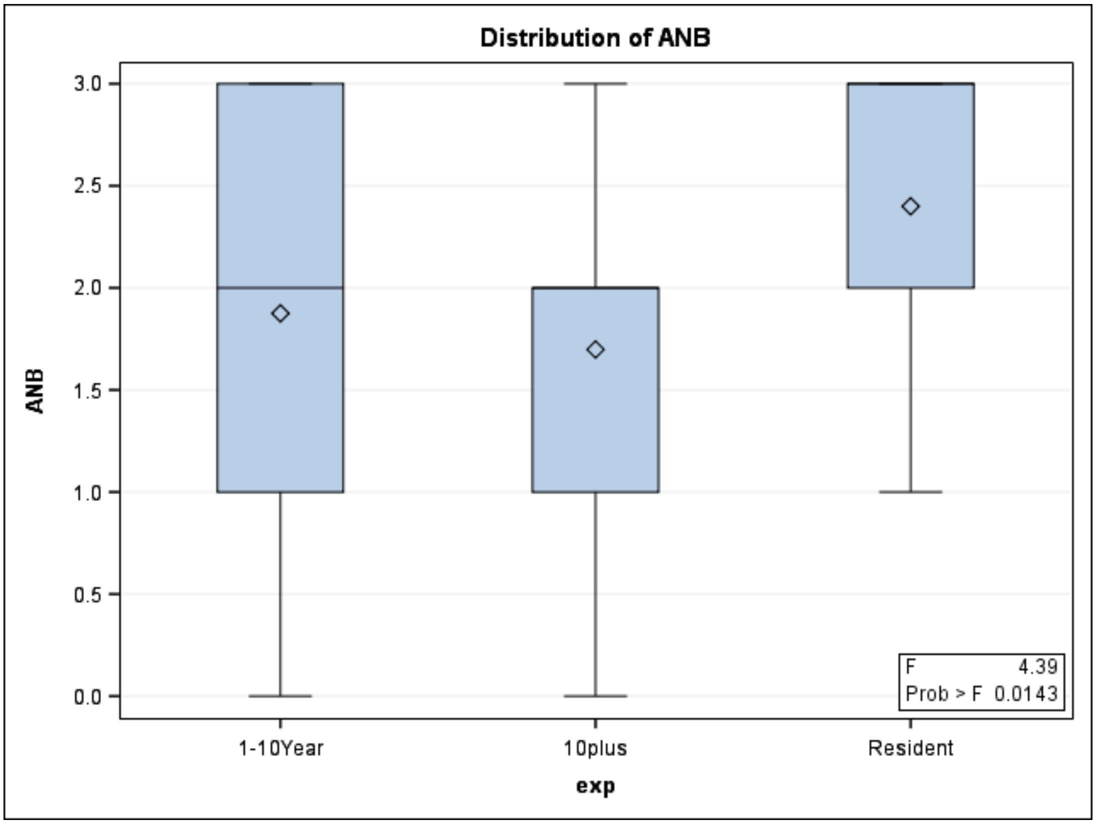


Figure 4. ANB Distribution. Distribution analysis based on the number of correct responses for ANB estimates for all three cases.

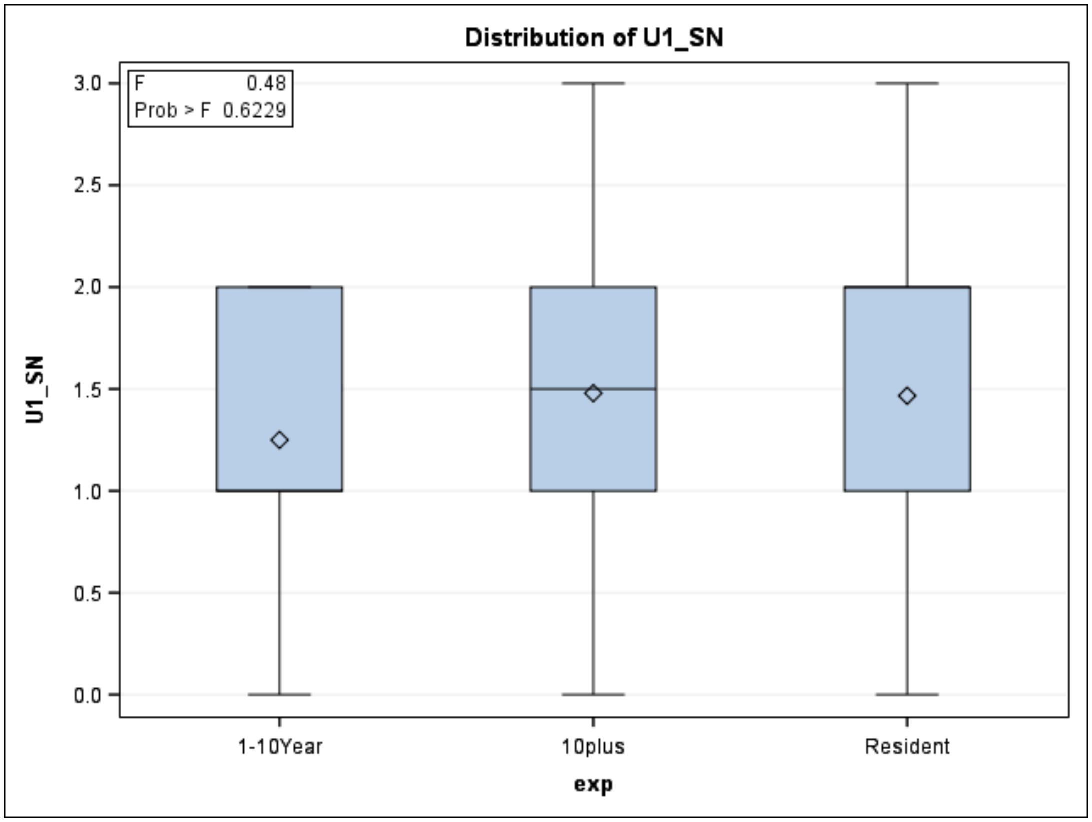


Figure 5. U1-SN Distribution. Distribution analysis based on the number of correct responses for U1-SN estimates for all three cases.

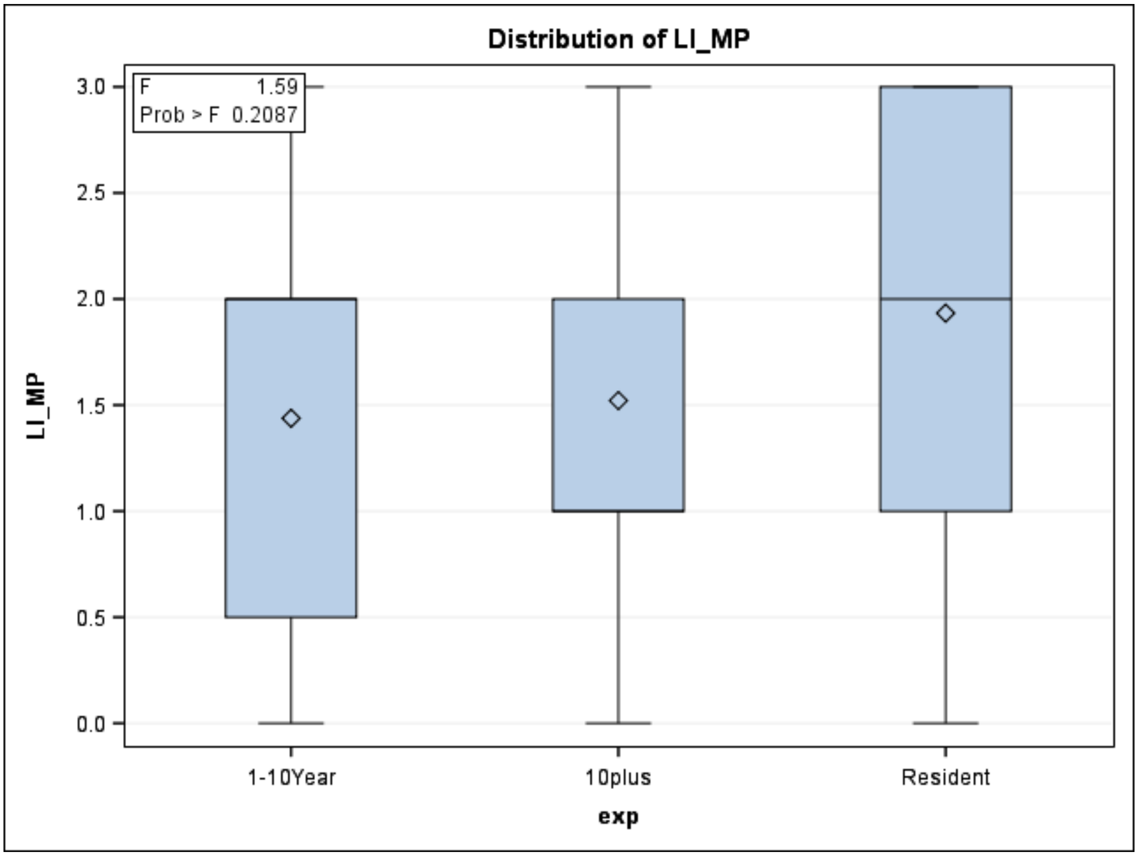


Figure 6. L1-MP Distribution. Distribution analysis based on the number of correct responses for L1-MP estimates for all three cases.

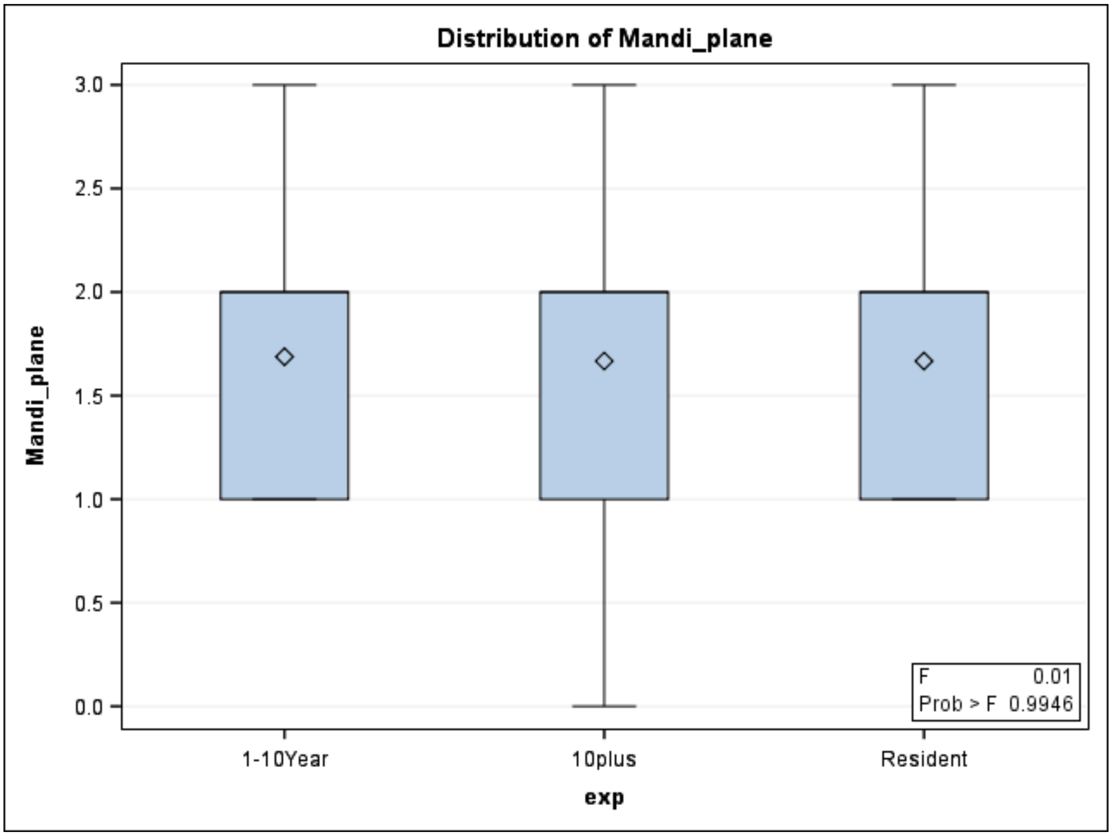


Figure 7. FMA Distribution. Distribution analysis based on the number of correct responses for FMA estimates for all three cases.

Table 12. Vertical Control Methods by Frequency.

	N (%)	HPHG	TPA	LLHA	TADs
Case 4		2 (1.6)	19 (15.0)	12 (9.4)	6 (4.7)
Case 5		34 (26.8)	60 (47.2)	23 (18.1)	71 (55.9)
Case 6		1 (0.8)	7 (5.5)	3 (2.4)	4 (3.1)

Visual Approximation Accuracy Associated with Expertise

One-way ANOVA tests were performed to compare participants' level of experience with accuracy. For each one of the six measurements, all three experience groups had similar values and distributions. There does not appear to be any correlation between level of expertise and accuracy when visually approximating dental crowding in occlusal photographs **(Table 13)**.

As the amount of crowding increased, those surveyed were more likely to choose a treatment option utilizing extraction. In Case 1, which had the least amount of crowding a high majority (96.1%) chose a non-extraction plan **(Table 14)**. As the amount of crowding increased, as in case number two, the number of practitioners who would treat by extraction decreased slightly to 81%. In both of these cases, most of those surveyed would address the crowding through transverse expansion. In all three cases, molar distalization was the least preferred treatment option to correct crowding **(Table 14)**.

Table 13. Arch Length Discrepancy and Level of Expertise. Relationship between accuracy and level of expertise when visually approximating arch length discrepancy. This table shows the results on one-way ANOVA analysis with three different groups of experience. Mean difference indicates between the estimated value and correct value. Positive values indicate overestimation and negative values indicate underestimation.

	Resident (N=15)		1-10 years (N=16)		>10 years (N=96)		P Value
Variable	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	
Case 1 Max	1.79	0.72	1.90	0.70	1.87	0.96	0.9448
Case 1 Mand	0.20	0.97	-0.19	1.07	-0.17	1.47	0.6193
Case 2 Max	2.36	1.95	3.11	3.06	2.61	3.66	0.8184
Case 2 Mand	3.73	1.03	3.64	0.94	3.67	1.89	0.9889
Case 3 Max	3.96	1.54	4.09	3.43	4.15	3.24	0.9745
Case 3	0.87	1.16	4.09	3.43	1.31	1.54	0.4766

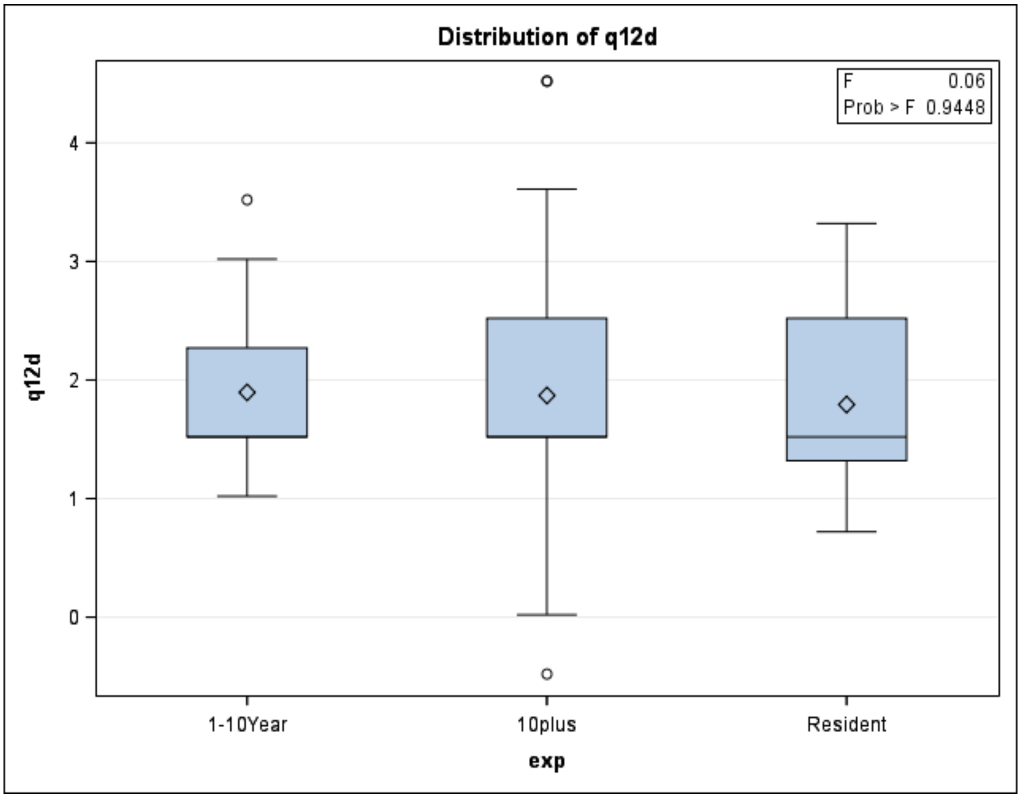


Figure 8. Case 1 Maxillary Crowding Distribution. Distribution of participants' visual crowding measurements for Case 1 maxillary photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

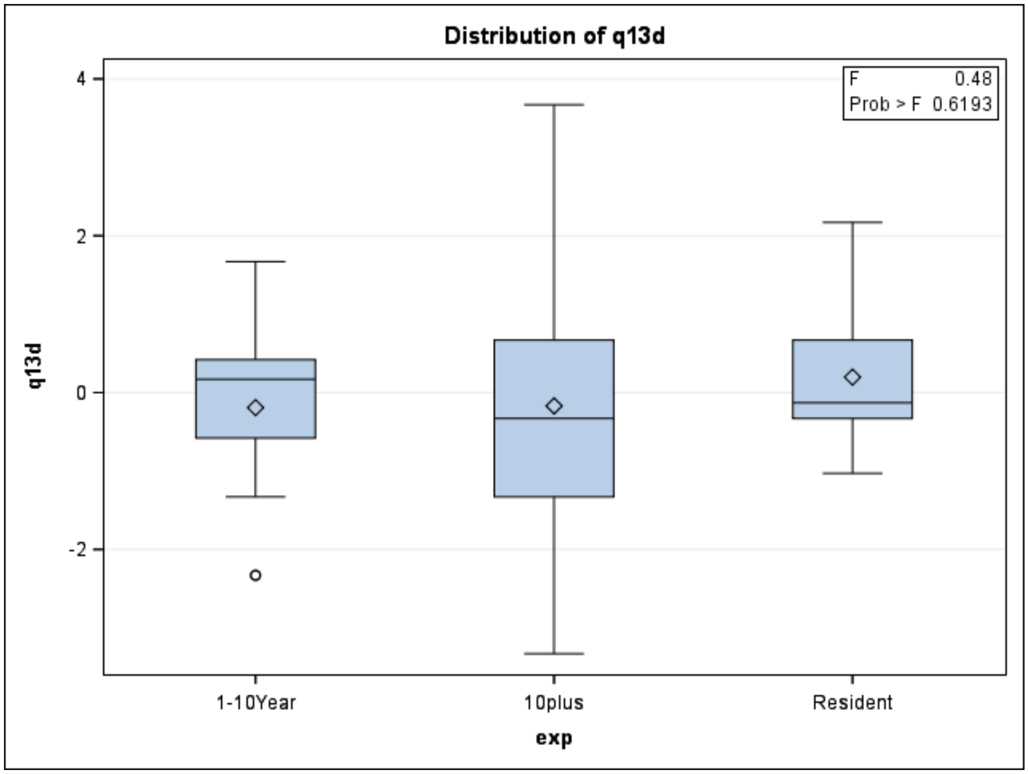


Figure 9. Case 1 Mandibular Crowding Distribution. Distribution of participants' visual crowding measurements for Case 1 mandibular photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

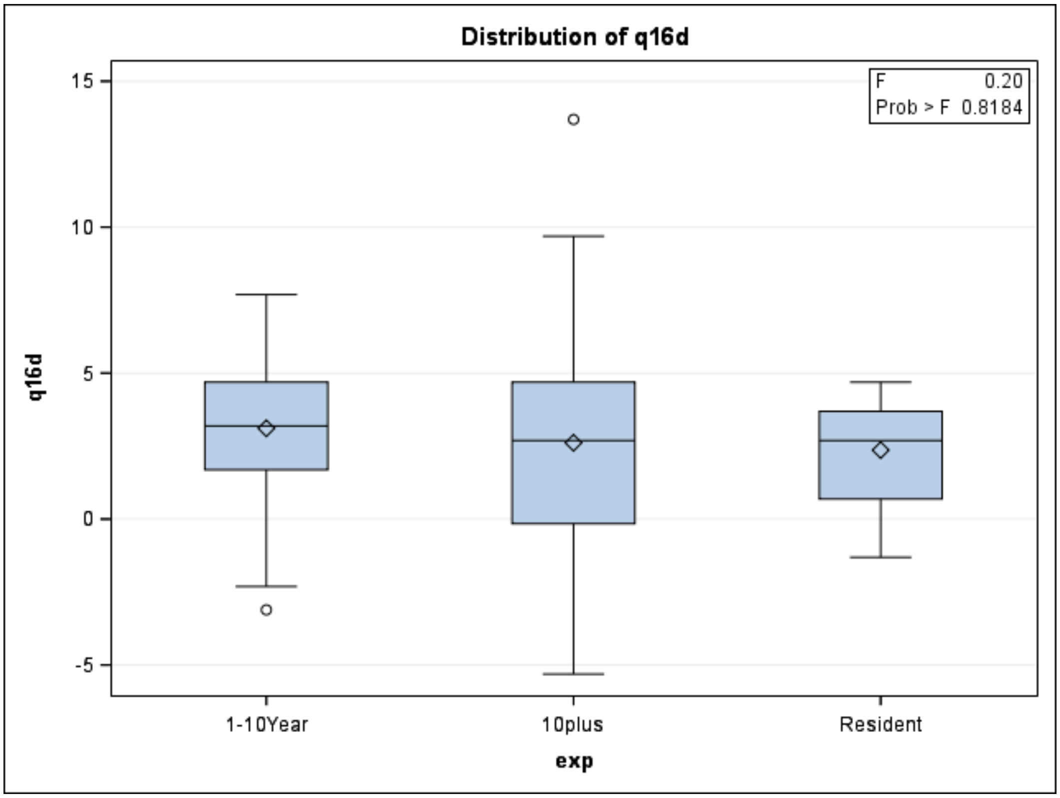


Figure 10. Case 2 Maxillary Crowding Distribution. Distribution of participants' visual crowding measurements for Case 2 maxillary photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

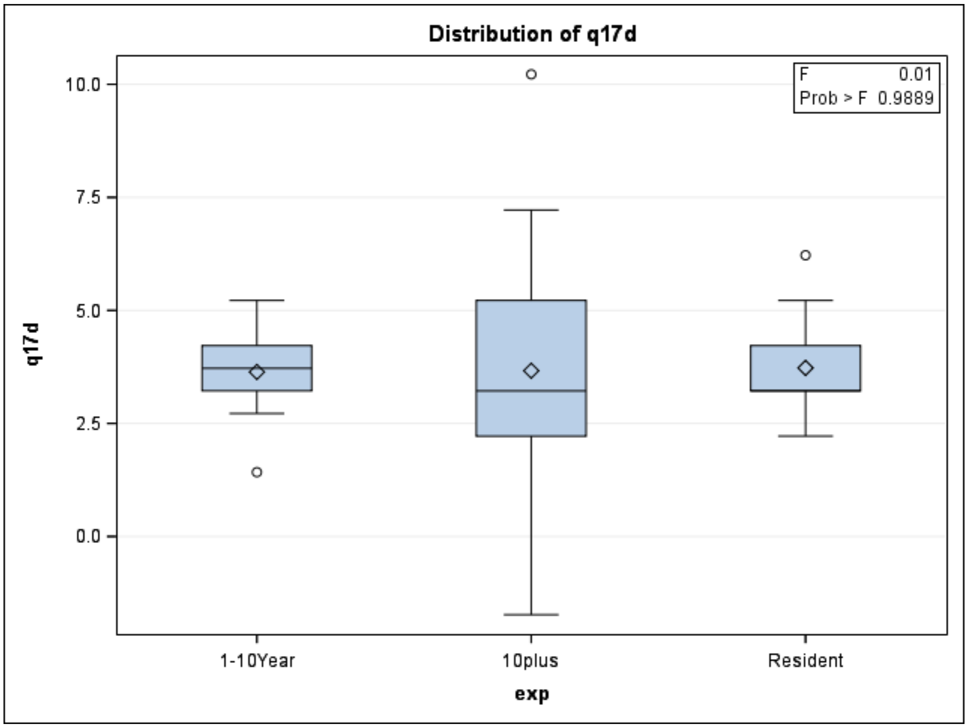


Figure 11. Case 2 Mandibular Crowding Distribution. Distribution of participants' visual crowding measurements for Case 2 mandibular photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

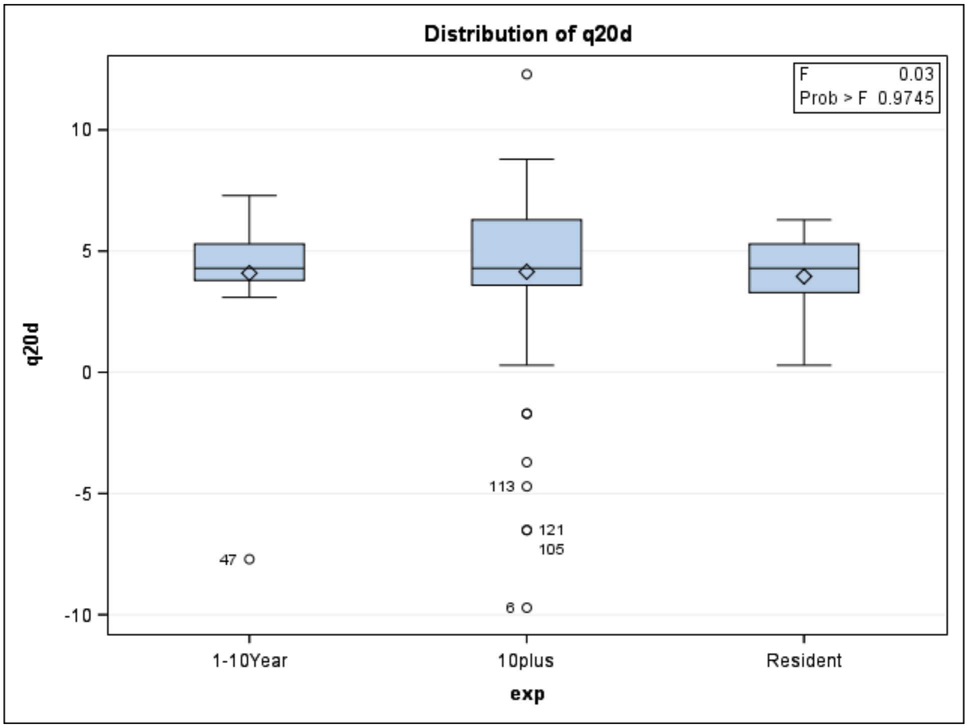


Figure 12. Case 3 Maxillary Crowding Distribution. Distribution of participants' visual crowding measurements for Case 3 maxillary photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

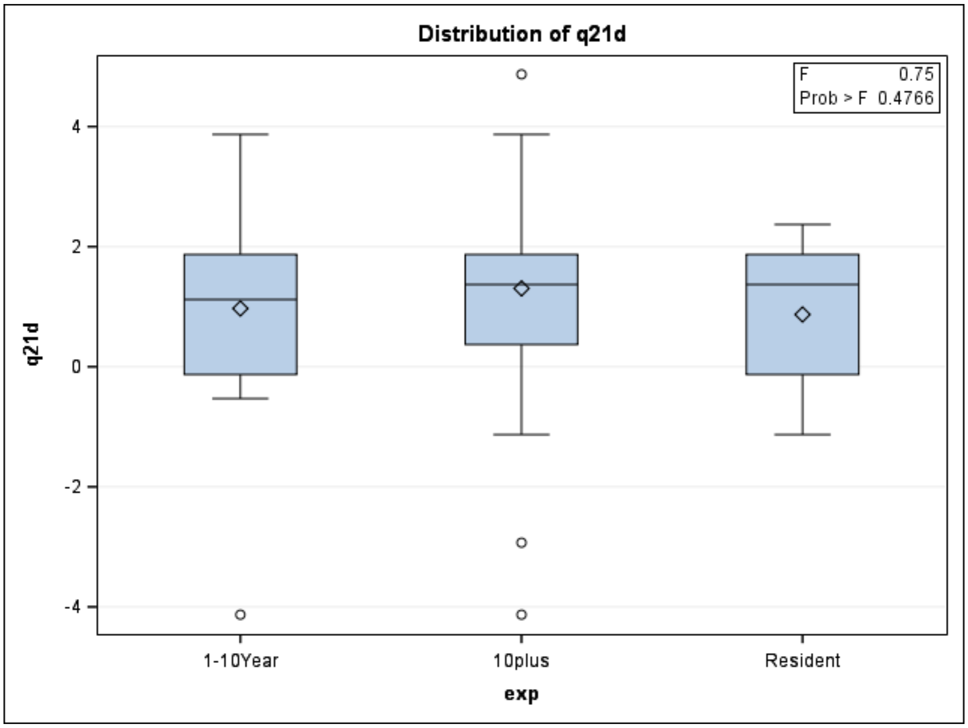


Figure 13. Case 3 Mandibular Crowding Distribution. Distribution of participants' visual crowding measurements for Case 3 mandibular photo. There is no significant difference in the average overestimation or underestimation based on level of experience.

Table 14. Non-extraction Treatment Mechanics. Frequency table analyzing the treatment Mechanics Chosen for Non-Extraction Treatment. Questions 14 and 15 of the survey refer to Case 1. Questions 18 and 19 refer to Case 2. Questions 22 and 23 refer to Case 3.

Case 1	**N**	**%**
Non-extraction	122	96.1
IPR	79	62.2
Transverse Expansion	90	70.9
Flare Incisors	51	40.2
Distalize Molars	20	15.7
Case 2		
Non-extraction	81	63.8
IPR	41	32.3
Transverse Expansion	80	63.0
Flare Incisors	46	36.2
Distalize Molars	27	33.9
Case 3		
Non-extraction	4	3.1
IPR	7	5.5
Transverse Expansion	6	4.7
Flare Incisors	5	3.9
Distalize Molars	5	3.9

Chapter V
DISCUSSION

The descriptive statistics in this study provided an interesting glance into the clinical practice of many orthodontists. However, the majority of participants in this study were male with more than ten years of experience, with only six respondents with six to ten years of experience. This uneven distribution may have some impact on the results. For example, although the majority of this sample rely on plaster models for space analysis, digital models are far more common among those with less experience **(Table 5)**. This is probably due to the technological advancements of the last ten years, giving younger practitioners better access to more reliable digital models. Digital models have be shown to provide a comparable level of accuracy compared to plaster models (Leifert et al.).

This may also explain why only 53.5% of those surveyed practice with clear aligners, as those are a relatively new technology experiencing rapid growth and high demand among the current patient population **(Table 5)**. There was also a trend towards the use of clinical photos and digital models as the level of experience decreased. This is most likely due to advances in technology, allowing for better digital representation of study models and cephalometric analyses. Visual approximation is the most popular method of determining arch length discrepancies among those surveyed, while manual measurement was the least commonly used **(Table 3)**.

Overall, practitioners' are not very accurate at visually approximating arch length discrepancies. In four of the six occlusal photos shown to participants, those surveyed over-estimated crowding on average by at least 1 mm **(Table 12)**. This confirms the finding of previous studies, which have concluded that orthodontists tend to overestimate the amount of crowding (Johal and Battagel; Wallis et al.; Naish et al.; Wurm). This study expands on past research by including clinical photos, as opposed to three-dimensional models. The mean over-estimation ranged from 0.20 mm, which was the arch with the least amount of crowding, to 5.09 mm of over-estimation, which was in the arch with the most crowding **(Table 12)**. There was a trend for the mean overestimation to increase across all groups as the amount of crowding increased. Based on these findings, there is no overall effect of experience on the ability to accurately visually approximate dental crowding.

In two of the three cases presented, the majority of participants chose a non-extraction treatment plan **(Table 13)**. When asked about specific treatment mechanics, transverse expansion was the most commonly selected method. IPR and incisor flaring were also chosen by a high number of participants. Molar distalization was universally the least chosen option. This may be due to the fact that participants were not given any means to evaluate the occlusal relationships of each case. In class II cases, molar distalization may be a good option, but if the patient is class III, molar distalization will be inefficient and worsen the original malocclusion. Unsurprisingly, as the perceived amount of crowding increased, so did the likelihood that participants' would choose to treat the case with extractions.

When visually approximating crowding, participants were instructed not to take into account the Curve of Spee, as this is not visible from occlusal photos. In addition, the occlusal relationships were not apparent based on the photos provided in this study. Neither of these factors can be accounted for in a computer program analysis. There have been previous studies which instructed orthodontists to take into account the Curve of Spee, but participants were provided with physical, three dimensional models to assess (Wallis et al.). Future studies could include lateral views that show the vertical dimension and allow participants to better take into account the Curve of Spee.

When visually approximating cephalometric measurements, on average about half of the participants tended to choose the correct range **(Table 6)**. In all but three of the measurements given, over 50% of participants accurately assessed the angle. In case 5, however, only 38% of participants correctly approximated U1-SN, and in case 6, there was a slight increase to 40% correctly approximating U1-SN. It is interesting to note that in two of the three cases, the minority of orthodontists could correctly estimate upper incisor angulations.

This study has expanded on a 2017 pilot study to determine how accurate practitioners are at visually approximating lateral cephalometric analyses (Wurm). These findings further confirm that practitioners are not very accurate at visually estimating cephalometric measurements. The accuracy rate for these measurements ranges from 67% to 38%, with an average accuracy rate of 54% **(Table 6)**. There was no clear pattern of overestimation or underestimation. This lack of a clear pattern may partially be explained by having participants choose from a range of measurements rather than inserting a more precise measurement. For example, whether the subject believes the measurement to be on the low or high end of the range provided, the response will be the same. In the U1-SN range, this difference could be as much as 11 degrees difference.

Overall, there is no significant correlation between the participants' level of expertise and the ability to visually approximate cephalometric measurements. In three of the four measurements analyzed, all had experience levels showed similar values and distributions. The hypothesis that practitioners are more accurate as clinical experience increases can be rejected in the context of this study. The exception to this conclusion is the visual approximation of ANB. Interestingly, the resident participants, with the least amount of clinical experience, were better at estimating the ANB than those with ten years or more of experience. This could be explained, in part, due to the fact that most residents routinely trace and analyze their own cephalograms on a more consistent basis. In private practice, this may be a task delegated to an assistant, and merely checked by the practitioner.

Visual estimation may have an impact on the vertical control chosen by the participants. In the cases presented with a higher than average mandibular plane angle, orthodontists were more likely to chose an extraction treatment plan and favor a maximum amount of vertical control **(Table 11)**. However, there was no clear pattern in terms of which appliance participants favored to deliver vertical control. In case 5, which presented the highest mandibular plane angle, more orthodontists selected TADs as part of their treatment mechanics. Lower lingual holding arch and transpalatal bar were favored more in the case 4, which presented a mesocephalic growth pattern. In case 6, a brachycephalic growth tendency was displayed, and the majority chose a non-extraction treatment plan in which vertical control was not necessary.

Future studies may solely focus on orthodontists' ability to visually approximate cephalometric measurements without formal analyses. In this study, participants were given a generous range to choose from for each measurement. When given a smaller range, accuracy may vary less and have more impact on the treatment plan. Additionally, the cases selected for this survey tended to fall specifically in one category (i.e., dolichocephalic, brachycephalic, etc). By presenting practitioners' with less polarizing options, it may be possible to better assess their accuracy. It may also be of interest to add more categories to determine the amount of practice experience of orthodontists. Since the vast majority of those in this study fell into one category, it may be helpful to stratify the data further by adding more categories for overall clinical experience.

Chapter VI
SUMMARY AND CONCLUSIONS

Orthodontists and orthodontic residents were given a survey to determine their ability to visually estimate arch length discrepancy and cephalometric measurements. Additionally, participants were surveyed on how these estimations would impact certain orthodontic treatment planning decisions. The survey also included a section on demographics, and participants were asked about routine practices.

On average, all visual approximations of crowding were larger than the true measurements. The mean amount of overestimation tended to increase as the amount of crowding increased. There was no clear significant association accuracy and level of expertise.

Overall, orthodontists are not accurate at visually approximating cephalometric angular measurements. There is no clear association between accuracy and level of expertise for three of the four measurements included in this survey. When visually estimating ANB, the orthodontic residents surveyed were more accurate than those with more clinical experience.

Conclusions:

1. When visually approximating arch length discrepancy in occlusal photos, orthodontists have a tendency to overestimate the amount of crowding present. Practitioners tend to overestimate more as the true amount of crowding increases.
2. As the amount of crowding increases, more orthodontists are likely to treat via extractions. When utilizing non-extraction treatment mechanics, transverse expansion was the most popular method, followed closely by IPR and incisor flaring.

3. Orthodontists are not accurate at visually approximating lateral cephalometric measurements.

4. When visually estimating ANB, orthodontic residents have a tendency to be more accurate than those with more clinical experience. This may partially be explained by the fact that all of the residents surveyed take and analyze a cephalogram on almost every patient.

5. As the FMA increases, more practitioners choose a treatment plan that entails maximum vertical control. The preferred method varies greatly, and there is no clear pattern that associates level of experience or accuracy to the appliance of choice.

6. In cases with a borderline amount of crowding present, orthodontists should evaluate the method used for space analysis. More formal measurements will provide a more accurate determination of arch length discrepancy, which may have some influence on the decision to extract.

7. When taking lateral cephalograms, the appropriate landmarks should be traced, followed by proper cephalometric analysis, in order to derive accurate measurements.

References

Al-Abdallah, M., J. Sandler, and K. O'Brien. "Is the Royal London Space Analysis Reliable and Does It Influence Orthodontic Treatment Decisions?" *Eur J Orthod* 30.5 (2008): 503-7.

Beazley, W. W. "Assessment of Mandibular Arch Length Discrepancy Utilizing an Individualized Arch Form." *Angle Orthod* 41.1 (1971): 45-54.

Bishara, S. E., J. M. Chadha, and R. B. Potter. "Stability of Intercanine Width, Overbite, and Overjet Correction." *Am J Orthod* 63.6 (1973): 588-95.

Broadbent, B. Holly. "A New X-Ray Technique and Its Application to Orthodontia." *The Angle Orthodontist* 1.2 (1931): 45-66.

de la Cruz, A., et al. "Long-Term Changes in Arch Form after Orthodontic Treatment and Retention." *Am J Orthod Dentofacial Orthop* 107.5 (1995): 518-30.

Devereux, L., et al. "How Important Are Lateral Cephalometric Radiographs in Orthodontic Treatment Planning?" *Am J Orthod Dentofacial Orthop* 139.2 (2011): e175-81.

Durão, A. R., et al. "Influence of Lateral Cephalometric Radiography in Orthodontic Diagnosis and Treatment Planning." *Angle Orthod* 85.2 (2015): 206-10.

Enlow, D. H. "A Morphogenetic Analysis of Facial Growth." *Am J Orthod* 52.4 (1966): 283-99.

Firouz, M., J. Zernik, and R. Nanda. "Dental and Orthopedic Effects of High-Pull Headgear in Treatment of Class Ii, Division 1 Malocclusion." *Am J Orthod Dentofacial Orthop* 102.3 (1992): 197-205.

Francisconi, M. F., et al. "Overjet, Overbite, and Anterior Crowding Relapses in Extraction and Nonextraction Patients, and Their Correlations." *Am J Orthod Dentofacial Orthop* 146.1 (2014): 67-72.

Han, U. K., et al. "Consistency of Orthodontic Treatment Decisions Relative to Diagnostic Records." *Am J Orthod Dentofacial Orthop* 100.3 (1991): 212-9.

Howe, R. P., J. A. McNamara, and K. A. O'Connor. "An Examination of Dental Crowding and Its Relationship to Tooth Size and Arch Dimension." *Am J Orthod* 83.5 (1983): 363-73.

Isaacson, J. R., et al. "Extreme Variation in Vertical Facial Growth and Associated Variation in Skeletal and Dental Relations." *Angle Orthod* 41.3 (1971): 219-29.

Jacobson, A. "The "Wits" Appraisal of Jaw Disharmony." *Am J Orthod* 67.2 (1975): 125-38.

Jacobson, Alexander. *Radiographic Cephalometry*. Carol Stream, IL: Quintesscence, 1995.

Johal, A. S., and J. M. Battagel. "Dental Crowding: A Comparison of Three Methods of Assessment." *Eur J Orthod* 19.5 (1997): 543-51.

Keim, R. G., et al. "2015 Jco Orthodontic Practice Study, Part 1 Trends." *J Clin Orthod* 49.10 (2015): 625-39.

Kravitz, N. D., et al. "The Use of Temporary Anchorage Devices for Molar Intrusion." *J Am Dent Assoc* 138.1 (2007): 56-64.

Kuhn, R. J. "Control of Anterior Vertical Dimension and Proper Selection of Extraoral Anchorage." *Angle Orthod* 38.4 (1968): 340-9.

Leifert, M. F., et al. "Comparison of Space Analysis Evaluations with Digital Models and Plaster Dental Casts." *Am J Orthod Dentofacial Orthop* 136.1 (2009): 16.e1-4; discussion 16.

Little, R. M., T. R. Wallen, and R. A. Riedel. "Stability and Relapse of Mandibular Anterior Alignment-First Premolar Extraction Cases Treated by Traditional Edgewise Orthodontics." *Am J Orthod* 80.4 (1981): 349-65.

Manosudprasit, A., et al. "Diagnosis and Treatment Planning of Orthodontic Patients with 3-Dimensional Dentofacial Records." *Am J Orthod Dentofacial Orthop* 151.6 (2017): 1083-91.

Mullen, S. R., et al. "Accuracy of Space Analysis with Emodels and Plaster Models." *Am J Orthod Dentofacial Orthop* 132.3 (2007): 346-52.

Naish, H., et al. "Does a True Knowledge of Dental Crowding Affect Orthodontic Treatment Decisions?" *Eur J Orthod* 38.1 (2016): 66-70.

Normando, D., P. L. da Silva, and ÁM Mendes. "A Clinical Photogrammetric Method to Measure Dental Arch Dimensions and Mesio-Distal Tooth Size." *Eur J Orthod* 33.6 (2011): 721-6.

Orthodontics, American Board of. "Construction of the Mandibular Plane." Habanero 2015. Web. April 15, 2018.

Pae, E. K., et al. "Role of Lateral Cephalograms in Assessing Severity and Difficulty of Orthodontic Cases." *Am J Orthod Dentofacial Orthop* 120.3 (2001): 254-62.

Proffit, William R, Henry W Fields, and David M Sarver. *Contemporary Orthodontics*. Vol. 5. St Louis, Missouri: Elsevier, 2013.

Schudy, F. F. "The Rotation of the Mandible Resulting from Growth: Its Implications in Orthodontic Treatment." *Angle Orthod* 35 (1965): 36-50.

Silling, G., et al. "The Significance of Cephalometrics in Treatment Planning." *Angle Orthod* 49.4 (1979): 259-62.

Steiner, Cecil C. "Cephalometrics for You and Me." *The American Journal of Orthodontics* 39.10 (1953): 729-55.

Tweed, C. H. "Indications for the Extraction of Teeth in Orthodontic Procedure." *Am J Orthod Oral Surg* 42 (1944): 22-45.

Uysal, T., et al. "Chronologic Age and Skeletal Maturation of the Cervical Vertebrae and Hand-Wrist: Is There a Relationship?" *Am J Orthod Dentofacial Orthop* 130.5 (2006): 622-8.

Villalobos, F. J., P. K. Sinha, and R. S. Nanda. "Longitudinal Assessment of Vertical and Sagittal Control in the Mandibular Arch by the Mandibular Fixed Lingual Arch." *Am J Orthod Dentofacial Orthop* 118.4 (2000): 366-70.

Wallis, C., et al. "How Good Are We at Estimating Crowding and How Does It Affect Our Treatment Decisions?" *Eur J Orthod* 36.4 (2014): 465-70.

Watson, D. H. "Cervical Traction and the Face Bow Orthodontic Applicance." *Int J Orthod* 6.2 (1968): 53-61.

White, L. W. "Accurate Arch-Discrepancy Measurements." *Am J Orthod* 72.3 (1977): 303-8.

White, S. C. "1992 Assessment of Radiation Risk from Dental Radiography." *Dentomaxillofac Radiol* 21.3 (1992): 118-26.

Wurm, Bradley J. "Direct Visual Approximation of Arch Length Discrepancy and Cephalometric Measurements." Marquette University, 2017.

Appendix A

Direct Visual Approximation of Arch Length Discrepancy and Cephalometric Measurements

The purpose of this study is to compare subjects' visual estimation of crowding and lateral cephalometric measurements with the true measurements computed using e-model and Dolphin Imaging software. Analysis will also determine if level of experience influences the accuracy of responses. Participation in this survey is voluntary with no known risks associated. Results will be anonymous and subjects will not be identified in any reporting of results.

* Required

1. By selecting "yes", I am indicating that I have read the above statement and that I will not discuss measurements with any previous or potential survey takers until after the completion of this study *

   Mark only oneoval.

- Yes, I agree
- No, I do not agree *Stop filling out this form.*

Descriptive Information

2. Gender *

   Mark only one oval.

- Mal
- e
- Fem
- ale

3. Age *

   Mark only one oval.

- <30
- 30-50
- >50

4. What is your current level of expertise? *

Mark only one oval.

- Resident
- 1-5 years practicing
- 5-10 years practicing
- >10 years practicing

5. How often do you check cephalometric tracings in making an orthodontic diagnosis *

Mark only one oval.

Rarely/Never
Only when unsure of
treatment (Almost) Every
patient

6. What method(s) of measurement do you often use for space analysis? (check all that apply) *

Check all that apply.

Visual
approximation
Manual
measurement
Computer estimate

7. What physical test(s) do you use for deciding to treat a case by extraction? (check all that apply) *

Check all that apply.

Dental casts
Clinical photos
Panoramic X-
ray
Cephalometric X-ray

8. Which of the following is the most important factor for you in considering

extraction? *

Mark only one oval.

- ⬭ Dental crowding
- ⬭ Facial profile
- ⬭ Skeletal pattern

9. What kind of dental cast do you commonly use? *

Mark only one oval.

- Plaster models
- Digital models
- I do not routinely use models

10. What orthodontic technique(s) do you often use in daily practice? (check all that apply)
*

Check all that apply.

- Traditional fixed
- appliances Clear
- aligners
- Lingual fixed appliances

11. In your opinion, how important is space analysis in making the orthodontic diagnosis?
*

Mark only one oval.

- Very important
- Somewhat
- Important Not
- important

Directions

The purpose of this study is to compare subjects' visual estimation of crowding and lateral cephalometric measurements with the true measurements computed using e-model and Dolphin Imaging software. Analysis will also determine if level of experience influences the accuracy of responses.

Case #1

For the following pictures of the occlusal view, please estimate the "within arch" space deficiency (crowding) in mm (Round to the nearest decimal, e.g., 2.0 mm or 3.2 mm). This should be a 2-dimensional measurement of arch length required minus current arch length. This measurement should NOT take into consideration the curve of Spee, curve of Wilson, inclination of teeth, etc.

12. Estimate maxillary crowding in mm (Please round to nearest decimal, e.g., 2.0 mm or **3.2 mm.) ***

13. Estimate mandibular crowding in mm. (Please round to nearest decimal, e.g., 2.0 mm or 3.2 mm.) *

14. Based on your visual estimation of space deficiency for the maxillary and mandibular arches, how would you choose to treat case #1?*

Mark only one oval.

- Extraction *After the last question in this section, skip to question 16.*
- Non-extraction

15. If non-extraction is chosen, which of the following procedures will you do? (check all that apply)

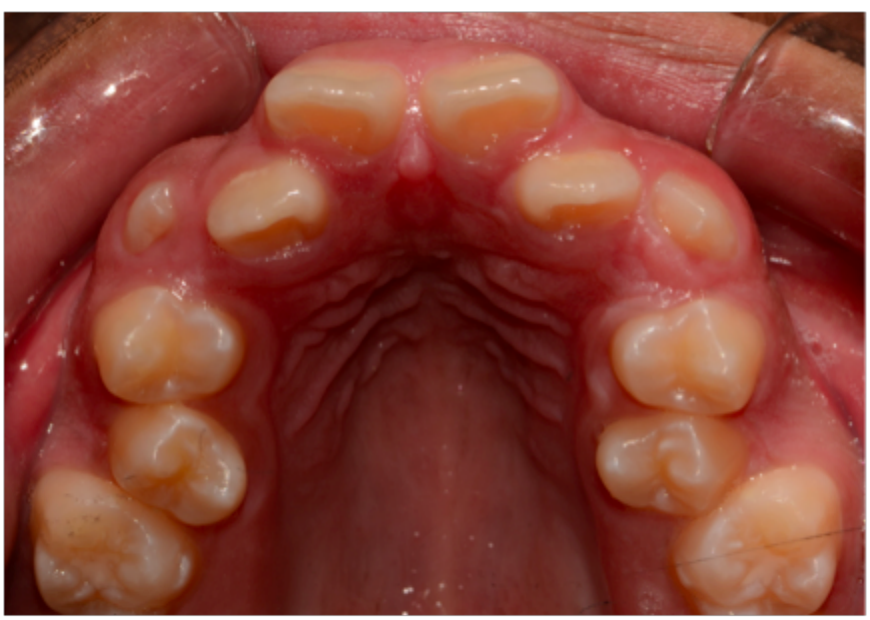
Check all that apply.

- [ ] IPR
- [ ] Transverse
- [ ] expansion Flare
- [ ] incisors Distalize

molars

Case #2

For the following pictures of the occlusal view, please estimate the "within arch" space deficiency (crowding) in mm (Round to the nearest decimal, e.g., 2.0 mm or 3.2 mm). This should be a 2-dimensional measurement of arch length required minus current arch length. This measurement should NOT take into consideration the curve of Spee, curve of Wilson, inclincation of teeth, etc.



16. Estimate maxillary crowding in

mm (Please round to nearest
decimal, e.g., 2.0 mm or
3.2 mm.) *

17. **Estimate mandibular crowding in mm (Please round to nearest decimal, e.g., 2.0 mm or 3.2 mm.) ***

18. **Based on your visual estimation of space deficiency for the maxillary and mandibular arches, how would you choose to treat case #2?***
Mark only one oval.

- ◯ Extraciton *After the last question in this section, skip to question 20.*
- ◯ Non-extraction

19. If non-extraction is chosen, which of the following procedures will you do? (check all that apply)
Check all that apply.

- ☐ IPR
- ☐ Transverse
- ☐ expansion Flare
- ☐ incisors Distalize

molars

Case #3

For the following pictures of the occlusal view, please estimate the “within arch” space deficiency (crowding) in mm (Round to the nearest decimal, e.g., 2.0 mm or 3.2 mm). This should be a 2-dimensional measurement of arch length required minus current arch length. This measurement should NOT take into consideration the curve of Spee, curve of Wilson, inclincation of teeth, etc.

20. Estimate maxillary crowding in mm (Please round to nearest decimal, e.g., 2.0 mm or 3.2 mm.) *

21. **Estimate mandibular crowding in mm (Please round to nearest decimal, e.g., 2.0 mm or 3.2 mm.) ***

22. Based on your visual estimation of space deficiency for the maxillary and mandibular arches, how would you choose to treat case #3?*

Mark only one oval.

- Extraction
- Non-extraction

23. If non-extraction is chosen, which of the following procedures will you do? (check all that apply)

Check all that apply.

- IPR
- Transverse expansion
- Flare incisors
- Distalize molars

Case #4

Please use your vision to estimate the measurements for the following lateral cephalogram. No other tools allowed.

24. ANB *

Mark only one oval.

- <-6°
- -6°-0°
- 0°-4°
- >4°-10°
- >10°

25. U1-SN *

Mark only one oval.

- <87°
- 87°-96°
- 97°-108°
- 109°-118°
- >118°

26. L1-MP *

Mark only one oval.

- <80°
- 80°-89°
- 90°-100°
- 101°-110°
- >110°

27. Mandibular plane to FH/FMA *

Mark only one oval.

- <13°
- 13°-20°
- 21°-29°
- 30°-37°
- >37°

28. Based on your visual estimation of maxillary and mandibular teeth, how would you choose to treat case #4? *

Mark only one oval.

- ( ) Extraction
- ( ) Non-extraction

29. Based on your visual estimate of the mandibular plane angle, what type of vertical control do you anticipate will be needed during treatment for the above patient? *

Mark only one oval.

- ( ) No vertical control needed
- ( ) Moderate vertical control
- ( ) Maximum vertical control

30. If vertical control is chosen, which of the following procedures will you do? (check all that apply) *

Check all that apply.

- [ ] High pull headgear
- [ ] Transpalatal bar
- [ ] Lower lingual holding arch
- [ ] TADs
- [ ] No vertical control needed

Case #5

Please use your vision to estimate the measurements for the following lateral cephalogram. No other tools allowed.

31. ANB *

Mark only one oval.

- <-6°
- -6°-0°
- 0°-4°
- >4°-10°
- >10°

32. U1-SN *

Mark only one oval.

- <87°
- 87°-96°
- 97°-108°
- 109°-118°

>118°

33. L1-MP *

Mark only one oval.

- <80°
- 80°-89°
- 90°-100°
- 101°-110°
- >110°

34. Mandibular plane to FH/FMA *

Mark only one oval.

- <13°
- 13°-20°
- 21°-29°
- 30°-37°
- >37°

35. Based on your visual estimation of maxillary and mandibular teeth, how would you choose to treat case #5? *

Mark only one oval.

- Extraction
- Non-extraction

36. Based on your visual estimate of the mandibular plane angle, what type of vertical control do you anticipate will be needed during treatment for the above patient? *

Mark only one oval.

- No vertical control needed
- Moderate vertical control
- Maximum vertical control

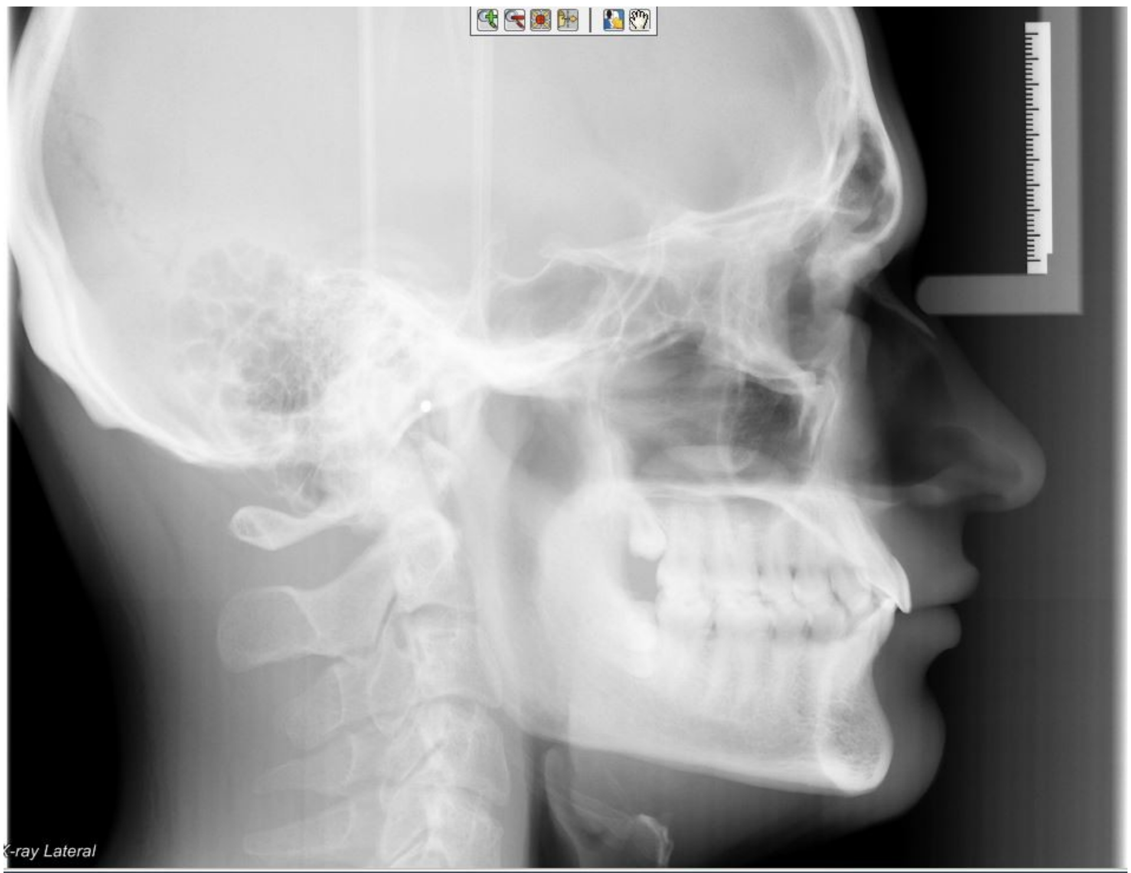
37. If vertical control is chosen, which of the following procedures will you do? (check all that apply) *

Check all that apply.

- [ ] High pull headgear
- [ ] Transpalatal bar
- [ ] Lower lingual holding
- [ ] arch TADs
- [ ] No vertical control needed

Case #6

Please use your vision to estimate the measurements for the following lateral cephalogram. No other tools allowed.



38. ANB *

Mark only one oval.

- <-6°
- -6°-0°
- 0°-4°
- >4°-10°
- >10°

39. U1-SN *

Mark only one oval.

- <87°
- 87°-96°
- 97°-108°
- 109°-118°
- >118°

40. L1-MP *

Mark only one oval.

- <80°
- 80°-89°
- 90°-100°
- 101°-110°
- >110°

41. Mandibular plane to FH/FMA *

Mark only one oval.

- <13°
- 13°-20°
- 21°-29°
- 30°-37°
- >37°

42. Based on your visual estimation of maxillary and mandibular teeth, how would you choose to treat case #6? *

Mark only one oval.

- Extraction
- Non-extraction

43. Based on your visual estimate of the mandibular plane angle, what type of vertical control do you anticipate will be needed during treatment for the above patient? *

Mark only one oval.

- No vertical control needed
- Moderate vertical control
- Maximum vertical control

44. If vertical control is chosen, which of the following procedures will you do? (check all that apply) *

Check all that apply.

- [ ] High pull headgear
- [ ] Transpalatal bar
- [ ] Lower lingual holding arch
- [ ] TADs
- [ ] No vertical control needed