Evaluation of Apical, Coronal and Occlusal Form Differences with Conventional Orthodontic Treatment

Tamar Sardarian
Loma Linda University
Evaluation of Apical, Coronal and Occlusal Form Differences with Conventional Orthodontic Treatment

by

Tamar Sardarian

A Thesis submitted in partial satisfaction of the requirements for the degree of Master of Science in Orthodontics and Dentofacial Orthopedics

August 2012
Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

______________________________, Chairperson
Joseph Caruso, Professor of Orthodontics and Dentofacial Orthopedics

______________________________
Mark Batesole, Assistant Professor of Orthodontics and Dentofacial Orthopedics

______________________________
V. Leroy Leggitt, Professor of Orthodontics and Dentofacial Orthopedics

______________________________
Kitichai Rungcharassaeng, Associate Professor of Orthodontics and Dentofacial Orthopedics
ACKNOWLEDGEMENTS

I would like to thank my committee members for their guidance and support throughout my research project. A special thank you to Dr. Batesole for allowing me to use his CephalometriX program and for all his time and effort in helping with my data analysis. To my family, I cannot thank you enough for all your encouragement and continued support.
CONTENTS

Approval Page........................................................................................................................................ iii

Acknowledgements ................................................................................................................................. iv

Contents .................................................................................................................................................. v

Figures................................................................................................................................................... vii

Tables ..................................................................................................................................................... viii

Abbreviations ........................................................................................................................................ ix

Abstract ................................................................................................................................................ x

Chapter

1. Introduction........................................................................................................................................1

   Statement of the problem ..................................................................................................................1
   Hypothesis .........................................................................................................................................1

2. Review of the Literature .................................................................................................................3

   Development of Arch Form .........................................................................................................3
   Arch Form in Different Malocclusions .........................................................................................4
   Alveolar Arch Form Differences ...................................................................................................5
   Clinical Implications ......................................................................................................................7
   CBCT .................................................................................................................................................8
   Euclidean Distance Matrix Analysis ............................................................................................9

3. Materials and Methods ..................................................................................................................11

   Statistical Analysis ....................................................................................................................21

4. Results .............................................................................................................................................22

   Reproducibility ............................................................................................................................22
   EDMA with Bootstrap Analysis ..................................................................................................22

5. Discussion ........................................................................................................................................26

   Statistical Significance ..................................................................................................................26
   Clinical Significance ......................................................................................................................27
Subject Demographic .................................................................28
Future Studies .................................................................29
Conclusions .................................................................30

References .................................................................31

Appendix

A. Reproducibility Data .................................................................35
B. Python Script to Extract XYZ Points .................................................................38
FIGURES

1. Frequency of Maxillary and Mandibular ALD in Millimeters .......................14
2. Landmark Selection in the CephalometriX™ Plugin Using MPR View ..........15
3. AP Landmark Selection in the CephalometriX™ Plugin Using MPR View ....16
4. Selection of CO Landmark for Upper Left First Molar ............................17
5. Selection of CO Landmark for Upper Right Central Incisor .....................18
6. OC Landmark for Lower Right Second Bicuspid .................................19
7. OC Landmark for Upper Right Central Incisor ..................................20
8. Results of EDMA with Bootstrap Analysis, Showing the Distribution and p-values of Each Sample .................................................................24
9. Visualization of Changes in Interlandmark Distances From T1 to T2 for Each Sample .................................................................25
# TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reproducibility – Overall Intraclass Correlation</td>
<td>22</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>ALD</td>
<td>Arch length discrepancy</td>
</tr>
<tr>
<td>AP</td>
<td>Apical</td>
</tr>
<tr>
<td>CBCT</td>
<td>Cone beam computed tomography</td>
</tr>
<tr>
<td>CO</td>
<td>Coronal</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>EDMA</td>
<td>Euclidean distance matrix analysis</td>
</tr>
<tr>
<td>FDM</td>
<td>Form difference matrix</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass correlation coefficient</td>
</tr>
<tr>
<td>MPR</td>
<td>Multi-planar reconstruction</td>
</tr>
<tr>
<td>OC</td>
<td>Occlusal</td>
</tr>
<tr>
<td>T1</td>
<td>Time point for pre-orthodontic treatment</td>
</tr>
<tr>
<td>T2</td>
<td>Time point for post-orthodontic treatment</td>
</tr>
</tbody>
</table>
ABSTRACT OF THE THESIS

Evaluation of Apical, Coronal and Occlusal Form Differences with Conventional Orthodontic Treatment

by

Tamar Sardarian

Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics
School of Dentistry, September 2012
Dr. Joseph Caruso, Chairperson

Introduction: Cone-beam computed tomography (CBCT) can be used to accurately identify dental landmarks in order to detect changes in dental arch forms.

Purpose: The objective of this study was to determine how apical, coronal and occlusal arch forms change following orthodontic treatment with fixed appliances and to establish a base for future studies.

Material and Methods: Maxillary and mandibular apical, coronal and occlusal landmarks of 27 subjects were selected on their respective CBCT images at two time points: pre-orthodontic treatment (T1) and post-orthodontic treatment (T2). Comparisons were made between the two time points to evaluate how each arch form changed following routine orthodontic treatment.

Statistical Analysis: Euclidean Distance Matrix Analysis (EDMA) with bootstrap analysis was used to assess changes in geometric form from T1 to T2 at each of the three levels. Landmark selection was repeated on 10 subjects and an intraclass correlation (ICC) was used to assess reproducibility.

Results: The mandibular apical arch showed statistically significant change in geometric form from T1 to T2. No statistically significant change was observed in the mandibular coronal and occlusal, as well as maxillary apical, coronal and occlusal arches.
Conclusion: During conventional orthodontic treatment of Class I, minimally crowded cases, selecting orthodontic arch wires according to the clinical coronal or occlusal arch form is viable.
CHAPTER ONE

INTRODUCTION

Statement of the Problem

The pre-treatment dental arch form is an important factor in the diagnosis and treatment planning of orthodontic patients. Many studies have tried to identify a single, unique shape that best fits the dental arch form of particular orthodontic samples in an attempt to provide the best alignment and stability. While many studies have focused on describing these arch forms via various methods, it’s also important to apply these methods to orthodontically treated patients in order to understand how these arch forms really change with treatment. With the emergence of cone beam computed tomography (CBCT), we are now able to accurately identify and evaluate changes in these arch forms at multiplanar levels. Understanding these changes can perhaps lead to more predictable and stable orthodontic results.

The objective of this study was to determine how apical, coronal and occlusal arch forms change following orthodontic treatment with fixed appliances. Furthermore, this study will serve as a base for future studies.

Hypothesis

The null hypothesis in this study was: There is no difference in the geometric form of the apical, coronal and occlusal arches following orthodontic treatment.
The alternative hypothesis was: There is a significant change in the geometric form of the apical, coronal and occlusal arches following orthodontic treatment.
CHAPTER TWO
REVIEW OF THE LITERATURE

Development of Arch Form

Arch form refers to the position of teeth contained within the alveolar bone and their relationship to one another as well as to the opposing arch. In the past, arch forms were classified according to their geometric shape, such as elliptical, parabolic, segments of circles joined to straight lines, and even as modified spheres.\(^1\) Raberin et al. later went on to group arch forms into two main groups, the stretched group, which included narrow and pointed arch forms, and the stocky group, which included wide, mid and flat arch forms.\(^2\) When studying the dental arches of untreated subjects, Ricketts developed a pentamorphic arch system that included five different types of arch forms: normal, tapered, narrow tapered, ovoid and narrow ovoid.\(^3\) These five arch forms, he believed, would fit all facial types. Today, many arch forms are defined by mathematical functions, such as the catenary curve and the cubic spline curve.\(^4\) Although many attempts have been made to try and identify a single, simple arch form that represents either the maxilla or the mandible, investigators have come to the conclusion that no such ideal arch form exists.\(^2,5\)

It is without doubt that certain anatomic factors dictate the natural arch form. Initial shaping of the arch form occurs by the configuration of the supporting bone\(^1\) and is further shaped by the oral muscles and intraoral functional forces, such as the muscles of mastication and those of occlusion.\(^6\) Stability of occlusion is achieved once the maxillary
and mandibular teeth are arranged in harmonious arch forms that are in equilibrium. \(^7\)

The dental arch forms continue to change as one grows, adapts and ages. Carter et. al. showed that decrements of up to 3 mm occur in the arch width, depth and perimeter in untreated subjects between late adolescence and the fifth or sixth decade of life. \(^8\)

Arch forms may also be subject to the unfavorable influence of abnormal functions of the orofacial complex, such as consistent mouth breathing, low tongue posture and abnormal swallowing patterns. A study by Melink et. al. showed that sucking habits also play a role in affecting arch form by finding a positive correlation between a prolonged pacifier sucking habit and smaller maxillary and larger mandibular arch widths. \(^9\)

**Arch Form in Different Malocclusions**

Analysis and evaluation of the arch forms of patients with Class I, Class II and Class III malocclusions have revealed consistent differences between them. \(^1,10,11\) Yet no one particular arch form has been found to be unique to each group.

In a study by Braun et. al., both the maxillary and mandibular dental arch forms of Class I, Class II, and Class III patients were evaluated for differences in arch depth and arch width. According to their results, the mandibular arch shape of Class II occlusions was on average 3 mm smaller in arch depth and 2.3 mm narrower in arch width than normal Class I arches. The mandibular arch shape of Class III occlusions, on the other hand, was about 3.3 mm smaller in arch depth and 2.1 mm wider beginning in the premolar area than the arch of Class I occlusions. When analyzing differences in the maxillary arch shape, the arch depths for all three occlusions were found to be about the same. However, Class II maxillary arches were on average 1.5 mm narrower beginning in the lateral incisor-canine area while Class III maxillary arches were on average 5.1 mm
wider than Class I widths. Qiong et. al. also added that patients with Class II division 1 malocclusions in particular have larger maxillary arches than Class I occlusion patients, but with a narrow posterior arch width that required expansion to harmonize with the mandibular arch. 

The etiology of the variations in arch form among the different malocclusions is primarily due to variations in growth and development of either the maxilla or the mandible. While Class II malocclusions result from a transverse deficit in the mandible, Class III malocclusions arise from a maxillary arch that’s insufficient in the transverse and sagittal dimensions. With these differences in mind, the orthodontist can customize the treatment that is to be rendered to patients with different malocclusions.

**Alveolar Arch Form Differences**

As discussed earlier, the natural position of teeth within the arch is directed by the underlying basal bone. With differences in the dental arch form of patients with different malocclusions evident, it’s certainly no surprise that alveolar arch forms will vary as well. Uysal et. al. examined alveolar arch widths in normal, Class II division 1, Class II division 2, and Class III malocclusions in an effort to explain differences in the dental arch form observed among these groups. He found that in both Class II division 1 and Class II division 2 occlusions, the maxillary and mandibular alveolar widths were significantly narrower than that of Class I occlusions. To compensate for this insufficient alveolar base, maxillary molars in Class II occlusions, especially in division 1 cases, tend to incline buccally. Similar observations were made in the maxillary alveolar widths of Class III occlusions, with all measurements being significantly narrower in comparison to the Class I group. However, Class III mandibular alveolar widths were significantly
larger than in the Class I group. These patients tend to have their maxillary teeth inclined lingually while their mandibular teeth are inclined buccally.\textsuperscript{13} With respect to basal bone in adolescents and adults, no significant differences between the two groups have been found.\textsuperscript{14}

With the basal bone playing an integral role in positioning of teeth within the arch, many investigators have attempted to use the alveolar arch form to predict the appropriate dental arch form. Ronay et. al. examined the mandibular dental arch form at points where orthodontic brackets would be placed clinically and at the level of the underlying apical base. It was concluded that although the mandibular arch cannot be classified according to one general shape, the apical base arch form strongly correlates with the clinical arch form in Class I patients and so can be used to predict an individualized dental arch form.\textsuperscript{15} The same prediction method has been found to be useful in Class II occlusions.\textsuperscript{16} However, it’s important to note that the points representative of the apical base in these studies were only estimates determined by the height of the mucogingival junction.

A study by Vanarsdall et. al. has shown that orthodontic treatment with standard edgewise appliances does not affect the width of the basal structure in either the mandible or the maxilla.\textsuperscript{17} For this reason, it has become even more critical to consider alveolar dimensions in treatment, especially since it is now known that the width of the bone can limit the amount of orthodontic tooth movement possible, with patients having narrow alveolar widths demonstrating less tooth movement and more iatrogenic consequences.\textsuperscript{18}
Clinical Implications

The size and shape of the arch affect the amount of space available, stability of the dentition, occlusion and esthetics. With orthodontic treatment using fixed appliances alone, the orthodontist can attain significant increases in the perimeter of the dental arches during the leveling and aligning phases of treatment, with one study reporting up to a 3.5 mm increase in the maxillary arch.\textsuperscript{19} This expansion will not only allow the orthodontist to gain space within the arch, but will produce what they believe to be a more esthetically pleasing result. Esthetics is a key factor in orthodontic treatment and can be influenced by arch form. Kokich was quick to point out that orthodontists are far more perceptive to changes in dental esthetics than both general dentists and laypeople.\textsuperscript{20} A study by Roden-Johnson et. al. showed that most orthodontists deem broader arches to be more attractive than narrower ones and so tend to expand them in an effort to produce what they perceive as the most esthetic result. Laypeople, on the other hand, didn’t have a strong preference for a particular arch form.\textsuperscript{21} This suggests that it may be wise for orthodontists to understand their patients’ esthetic concerns and expectations prior to expanding arches for purely esthetic reasons.

With so many changes being made to the arch form with orthodontic treatment, one questions the long term stability of these changes. The stability of expanded arches is usually compromised. When dental arch forms are changed with treatment, there is a strong tendency for it to return back to its pre-treatment shape following the post-retention period. The greater the amount of change made, the greater this tendency for relapse.\textsuperscript{22} A study by Felton et. al. reported that about 70% of cases that undergo arch form changes are not stable and result in post-treatment changes.\textsuperscript{23} In particular, arch expansion has been found to be more stable in non-extraction than in extraction cases and
more so in the posterior region, while the least amount of stability is expected in the expansion of lower intercanine arch width.\textsuperscript{24} As for long-term stability, a longitudinal study by Ward et. al. showed that patients treated orthodontically will have a statistically significant increase in maxillary intercanine arch width, a decrease in maxillary and mandibular intermolar widths, and a decrease in mandibular intercanine arch width,\textsuperscript{15} suggesting the instability of altered arch form over time. 

As discussed earlier, the alveolar bone imposes a biologic limit on the amount of tooth movement possible by limiting the size of the arch. If teeth are moved beyond this limit, tipping of teeth, loss of attachment and other periodontal problems, and unstable treatment results with subsequent relapse are likely to ensue.\textsuperscript{15,26} In addition to causing deleterious tissue effects and compromising post-treatment stability, increasing the arch width beyond that of the natural form can also affect lip support and facial esthetics.\textsuperscript{26} These unfavorable consequences of over expansion of the dental arch must be kept in mind throughout treatment.

To date, no studies have been done accurately locating and evaluating the changes in the geometric form of the dental arches brought about by orthodontic treatment. With the development of cone beam computed tomography, evaluating dental arch forms more comprehensively has become possible, making it an important tool in orthodontic diagnosis and treatment planning.

\textbf{CBCT}

Many advances have been made within the field of imaging. In the past, the use of new and emerging imaging tools by orthodontists has been limited due to concerns with cost, efficiency and radiation exposure. However, with the development of the cone
beam computed tomography (CBCT), more and more dental practitioners are using this 3-dimensional imaging system in their diagnosis and treatment planning. CBCT is highly recommended for evaluation of impacted teeth, the TMJ, airway and maxillofacial growth in orthodontics.\textsuperscript{27} It has truly proven to be a comprehensive imaging modality.

CBCT can provide images with high diagnostic quality and high resolution in a 10 to 70 second scan. Furthermore, it can produce a 3-dimensional image with minimal distortion, making it a unique tool for the orthodontist to use in treatment planning. The advantages of CBCT are plentiful. In addition to the aforementioned, CBCT also provides image accuracy, has a rapid scan time, and reduces image artifacts, allowing for unprecedented evaluation of anatomic structures.\textsuperscript{28} CBCT has also proven to be an extremely useful tool for evaluating bone\textsuperscript{29} and is routinely used to evaluate implant sites. With such accurate images, studies have shown that measurements made from these CBCT volumes can accurately be used for quantitative analysis.\textsuperscript{30} The accuracy with which CBCT can identify various anatomical structures and relationships can certainly help improve diagnosis, treatment planning, and prognosis in orthodontics.\textsuperscript{31}

One concern with the use of CBCT in orthodontics has been the radiation dose. The radiation dose of CBCT is reduced and is markedly lower than that of a CT scan\textsuperscript{27,28} and so is the preferred method for when 3-dimensional imaging is required.

**Euclidean Distance Matrix Analysis**

Several different methods for evaluating changes in geometric form have been proposed.\textsuperscript{32,33,34} However, Euclidean Distance Matrix Analysis (EDMA) has been deemed most suitable for evaluating landmark data. It has been used extensively in craniofacial morphology studies such as growth studies,\textsuperscript{35,36,37} analysis of dental arch
EDMA is a statistical analysis that separates size from shape and allows changes in shape or form to be measured as a displacement of a landmark relative to all other landmarks. It attempts to describe change in form in terms of the entire shape and localizes areas of major change. In this analysis, a form matrix of the distances between the landmarks in a sample is calculated. The form matrices of two samples are then compared by the calculation of a form difference matrix (FDM), which is a ratio of one form matrix to the other. If no difference exists between two landmarks, the FDM value is 1.00. A value greater or less than 1.00 indicates the distance between the landmarks increased or decreased respectively. An advantage to this method is that the matrix is independent of translation or rotation, with the distances between the landmarks being the same regardless of the orientation of the landmark coordinate system. Furthermore, the error around one landmark is added to the errors of the others using superimposition methods. To test the results, a nonparametric bootstrap method is used. While most of the studies utilizing this method have been used to evaluate differences in the dental arch form of different malocclusions, to our knowledge there has been no research utilizing this method to evaluate changes in the position of both dental crowns and roots resulting from orthodontic treatment.
CHAPTER THREE
MATERIALS AND METHODS

T1 and T2 CBCT images of thirty subjects treated at the Loma Linda University graduate orthodontic clinic were selected according to the following criteria:

1. Complete orthodontic treatment with fixed appliances
2. Complete maxillary and mandibular permanent dentition from right to left first molar
3. Non-extraction, non-expansion, non-surgical treatment
4. Class I skeletal and dental

All subjects were at least eleven years old and had, on average, mild arch length discrepancies (ALD) with either mild crowding or mild spacing in each arch as shown in Figure 1. In addition, all subjects were treated with 0.018 slot Ricketts prescription brackets and all but the mandibular arch of one subject were treated with either 16x22 or 16x16 archwires at some point during treatment.

The images of three subjects were excluded due to motion artifacts. Thus, the CBCT images of twenty seven subjects were evaluated and analyzed. All CBCT images were taken with the NewTom 3G (12-bit). The images were imported into the NNT program (QR srl, Verona, Italy) and oriented to the occlusal plane. The images were then saved and exported to the OsiriX program, where they were subsequently anonymized.

The maxillary and mandibular landmarks at the apical (AP), coronal (CO), and occlusal (OC) levels were selected on each image using a plugin for OsiriX (open-source, www.osirix-viewer.com) called CephalometriX™. This plugin allows for points to be
selected in the axial, coronal and sagittal planes simultaneously, as shown in Figure 2. Our method involved navigation through the axial, coronal and sagittal planes until the proper landmark was found and confirmed in all three planes. The landmarks for each arch were selected from first molar to contralateral first molar as follows:

- **Apical level:** The root apex of each root was selected in the axial view at the most apical level where the root apex was visible. The point was then confirmed to be the geometric center of each root in the coronal and sagittal views. All roots of all teeth were selected. For multi-rooted teeth, the apex of each root was selected and the geometric center extrapolated for analysis. For example, the mesial, distal and palatal root apices of the maxillary first molar were selected. For the maxillary first bicuspid, CephalometriX was programmed to select a point for the buccal apex and a point for the lingual apex. In the case that the upper first bicuspid was single rooted, the apex of the single root was selected for both the buccal and lingual apical landmarks. An example of landmark selection at the apical level is shown in Figure 3.

- **Coronal level:** Landmarks were chosen to mimic the archwire slot as described by Andrews. For the first molars, the height of contour of the crown in line with the mesiobuccal groove of the mandibular molars and buccal groove of the maxillary molars was selected (Figure 4). For all other teeth, the height of contour or the midpoint of the facial axis of the crown was selected (Figure 5).

- **Occlusal level:** For both the mandibular and maxillary arches, the mesiobuccal cusp tip of the first molars, the buccal cusp tip of the premolars, and the cusp tip of the cuspids were selected. Figure 6 shows an example of the occlusal
landmark for the lower right second bicuspid. For the incisors, the midpoints of the incisal edges were selected in both the maxillary and mandibular arches (Figure 7). The locations of these points were confirmed in all three views.
Figure 1. Frequency of maxillary and mandibular ALD in Millimeters.
Figure 2. Landmark Selection in the CephalometriX™ Plugin Using MPR View. This plugin allows for a landmark to be selected and viewed in the axial, coronal and sagittal planes simultaneously.
Figure 3. AP Landmark Selection in the CephalometriX™ Plugin Using MPR View. In this example, the distal root of the lower left first molar has been selected, with the axial, coronal and sagittal planes passing through the most apical point of the root.
Figure 4. Selection of CO Landmark for Upper Left First Molar. The red dot represents the landmark at the height of contour of the crown.
Figure 5. Selection of CO Landmark for Upper Right Central Incisor. The red dot represents the landmark at midpoint of the facial axis of the crown.
Figure 6. OC Landmark for Lower Right Second Bicuspid. The buccal cusp tip of the bicuspid has been selected, as indicated by the red dot.
Figure 7. OC Landmark for Upper Right Central Incisor. The midpoint of the incisal edge has been selected, as indicated by the red dot.
Statistical Analysis

A Python computer script was used to extract the x, y and z coordinates of each point and run a three-dimensional Euclidean Distance Matrix Analysis with bootstrap analysis.

Landmark selection for the first molar, second bicuspid, canine, and central incisor on the right side of the dentition in both arches was repeated once on ten randomly selected subjects two months after initial landmark selection. An intraclass correlation (ICC) was used to assess reproducibility.
CHAPTER FOUR

RESULTS

Reproducibility

The overall ICCs at 95% confidence intervals are shown in Table 1. The results show excellent reproducibility in all sectors (x,y,z), with the single ICCs being equal to 1.0 and very tight 95% confidence intervals. The stratified ICCs and 95% confidence intervals can be found in the appendix.

Table 1. Reproducibility – Overall Intraclass Correlation

<table>
<thead>
<tr>
<th>Sector</th>
<th>Single Measures ICC</th>
<th>95% Confidence Interval</th>
<th>F Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>X</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
</tr>
<tr>
<td>Y</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Z</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
</tr>
</tbody>
</table>

EDMA with Bootstrap Analysis

The distribution of each sample along with the corresponding p-values resulting from the EDMA with bootstrap analysis is shown in Figure 8. As indicated by the p-values, a statistically significant change in geometric form from T1 to T2 is seen in the mandibular arch at the apical level. The mandibular coronal and occlusal, along with the maxillary apical, coronal and occlusal arches show no statistically significant change.
Localization of the changes in geometric form from T1-T2 in each arch and level can be visualized in Figure 9. These figures show changes in the interlandmark distances from T1 to T2, with the colors of the interlandmark lines corresponding to an increase or decrease in distance. Colors towards the blue end of the spectrum indicate the distance increased, green indicates the distance stayed the same, and colors towards the red end of the spectrum indicate the distance decreased.
Figure 9. Visualization of Changes in Interlandmark Distances From T1 to T2 for Each Sample. Legend shows magnitude of change according to ratio of T2 to T1 interlandmark distances and is scaled to maximally show differences. A) Maxillary arch, apical level. B) Mandibular arch, apical level. C) Maxillary arch, coronal level. D) Mandibular arch, coronal level. E) Maxillary arch, occlusal level. F) Mandibular arch, occlusal level.
CHAPTER FIVE
DISCUSSION

According to literature, EDMA is an effective and suitable analysis for evaluating landmark data.\textsuperscript{35,44} As discussed earlier, several studies have used this analysis to evaluate arch forms\textsuperscript{38,39,40,41}, growth changes\textsuperscript{35,36,37}, results of orthognathic surgeries and treatment with orthodontic functional appliances.\textsuperscript{42,43} However, there has been no research utilizing this method to evaluate changes in the position of both dental crowns and roots resulting from orthodontic treatment with fixed appliances. Furthermore, these studies have used casts and lateral cephalometric tracings to evaluate differences or changes. By using CBCT images, this study accurately identifies appropriate landmarks and provides unprecedented insight into the dental changes that occur following orthodontic treatment with fixed appliances.

\textbf{Statistical Significance}

The results from the EDMA with bootstrap analysis indicate a statistically significant change in geometric form from T1 to T2 in the mandibular arch at the apical level under the conditions of this study. The mandibular coronal and occlusal, along with the maxillary apical, coronal and occlusal arches show no statistically significant change in geometric form from T1 to T2.
Clinical Significance

When looking at the changes occurring in the mandibular apical arch, figure 9B shows that the distance between the posterior landmarks decreases mesiodistally from T1 to T2 whereas the distance between the anterior landmarks increases. Clinically, this is consistent with the posterior apices converging anteroposteriorly and the anterior apices diverging mesiodistally. This may be a result of the leveling of the curve of spee, a routine part of orthodontic treatment that involves extruding the posterior teeth and intruding the anterior teeth. This is supported by a study by Clifford et. al. that showed the molar roots moving mesially during leveling by a reverse curve archwire.45

The maxillary apical arch (Figure 9A) shows somewhat similar changes to those seen in the mandibular apical arch, with the posterior apices getting closer together and the anterior apices getting farther apart from T1 to T2. However, these changes were not found to be statistically significant. This may be due to the maxillary arch having a much larger volume than the mandibular arch. Thus, small changes may not be as readily observed in the maxilla whereas the smaller volume of the mandibular arch allows for the influence of the environment to be picked up more easily. In other words, variance in the mandibular arch is tighter.

According to Figure 9C and 9D, the maxillary and mandibular coronal arches show an increase in the posterior transverse dimension from T1 to T2. Furthermore, the mandibular coronal arch shows an increase in the anteroposterior dimension, consistent with an increase in arch depth. All these changes can be attributed to the rounding out of the arch during the leveling and aligning phase of orthodontic treatment.

The results for the maxillary and mandibular occlusal arches as seen in Figure 9E and 9F are very similar to the results seen in their respective coronal arches. This result
was expected as the landmarks for these two levels were very close together in space. As mentioned earlier, no statistically significant change was observed in either of these two levels. This may be due to biological limits to coronal tooth movement, such as lip or tongue pressure, as well as to the mere fact that the subjects used in this study had mild ALD and so limited tooth movement was required during orthodontic treatment.

The results of this study have direct implications in the clinical practice of orthodontics. The findings are clinically useful in helping the orthodontist decide which arch form to follow when selecting the orthodontic arch wire. Orthodontists would like to follow the arch form that’s most stable. Since significant change is seen in the mandibular apical arch, this arch form should not be followed. As no change is seen in the mandibular occlusal and coronal as well as the maxillary apical, coronal and occlusal arches, any one of these arches could technically be followed when selecting the arch form of the orthodontic arch wire. However, the apical arch is not clinically practical as it can only be determined radiographically. Since the coronal arch form is more reflective than the occlusal arch form of where the arch wire will be, selecting the clinical arch wire according to the clinical coronal arch form is viable.

**Subject Demographic**

As mentioned earlier, all subjects in this study were treated with 0.018 slot Ricketts prescription brackets and all but the mandibular arch of one subject were treated with either 16x22 or 16x16 archwires at some point during treatment, allowing for the torque in the brackets to be expressed to some degree, but not to their fullest extent. A fully filled slot may show greater differences. Furthermore, the subjects had, on average, mild ALDs with either mild crowding or spacing in each arch as shown in Figure 1.
Interestingly, examining the distribution of the ALD in each arch, one can see that while the mandibular arch had predominantly negative ALDs, indicative of crowding, the maxillary arch had an even distribution of negative and positive ALDs, indicating cases of both crowding and spacing. This may have confounded the results seen in the maxillary arch. A larger sample size that would allow for evaluation and analysis of only crowded cases in the maxillary arch may show results at the apical level similar to those seen in the mandibular arch.

With respect to age, all subjects were at least eleven years old. One may wonder if growth would influence the results of this study. While skeletal anteroposterior growth would not have an influence on the results, since each arch was evaluated independently, significant transverse growth would. However, according to literature, transverse growth of both jaws is minimal between seven and fifteen years of age. Furthermore, a deceleration in the increase in intermolar width after age eleven was reported, with 95% of intermolar width increases occurring by age seven.46,47

Given this subject demographic, one can see that the results of this study are specific to a particular subset of orthodontic patients. Furthermore, it’s difficult to separate the effects of certain variables on the results of the study. For example, incorrect bracket positioning, finishing bends, and additional archwire torque may all influence the final position of the roots or crowns at T2.

**Future Studies**

The results of this study provide insight into the dental changes occurring as a result of orthodontic treatment with fixed appliances. However, as discussed earlier, the results of this study are specific to a particular orthodontic patient population. The next step of
the study would be to analyze changes in geometric form in patients with different malocclusions as well as different treatment modalities, such as expansion via different appliances like the hyrax and quad helix, extraction, and surgery. Compared with the results of this study, these future studies would enable the clinician to see the effects of different treatments on arch form, allowing the clinician to determine if the changes, if any, are desired. Thus, the clinician can make treatment decisions that are best and most suitable for each patient. In turn, this may lead to more predictable and stable orthodontic results.

Finally, future studies should include evaluating these subjects during retention. Arch form may be changed during orthodontic treatment with different appliances. The clinician’s decision to do so depends on whether or not the changes are stable long-term. Thus, retention is a critical consideration and a study that evaluates post-retention cases would be a great complement to this study.

Conclusions

The following conclusions can be drawn based on the results seen in this study:

1. A significant change in the geometric form of the mandibular apical arch occurs in patients treated with orthodontic fixed appliances.

2. Selecting the clinical arch wire according to the clinical coronal arch form is viable in patients with Class I occlusions and ALD of -4 mm to +4 mm in the maxillary arch and -4 mm to +3 mm in the mandibular arch.

3. This study serves as a baseline for future studies examining subjects with different occlusions and treatment modalities. It also provides a method to collect and analyze data in such future studies.
REFERENCES


### Stratified “X” Sector Intraclass Correlation

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Single Measures ICC</th>
<th>95% Confidence Interval</th>
<th>F Test</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal AP LR6</td>
<td>0.998</td>
<td>0.996</td>
<td>0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP LR6</td>
<td>0.998</td>
<td>0.996</td>
<td>0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR5</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR3</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR1</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Distal AP UR6</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP UR6</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Palatal AP UR6</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR5</td>
<td>0.998</td>
<td>0.994</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR3</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR1</td>
<td>0.999</td>
<td>0.996</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR6</td>
<td>1.000</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR5</td>
<td>0.999</td>
<td>0.996</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR3</td>
<td>0.999</td>
<td>0.995</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR1</td>
<td>1.000</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR6</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR5</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR3</td>
<td>0.999</td>
<td>0.995</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR1</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR6</td>
<td>0.995</td>
<td>0.982</td>
<td>0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR5</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR3</td>
<td>0.999</td>
<td>0.995</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR1</td>
<td>1.000</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR6</td>
<td>0.999</td>
<td>0.995</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR5</td>
<td>1.000</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR3</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR1</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Stratified “Y” Sector Intraclass Correlation

<table>
<thead>
<tr>
<th>Sector</th>
<th>ICC Measures</th>
<th>95% Confidence Interval</th>
<th>F Test Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal AP LR6</td>
<td>0.999</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP LR6</td>
<td>0.999</td>
<td>0.997 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR5</td>
<td>0.999</td>
<td>0.997 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR3</td>
<td>0.998</td>
<td>0.994 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR1</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Distal AP UR6</td>
<td>1.000</td>
<td>1.000 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP UR6</td>
<td>1.000</td>
<td>1.000 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Palatal AP UR6</td>
<td>1.000</td>
<td>0.998 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR5</td>
<td>0.999</td>
<td>0.998 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR3</td>
<td>0.997</td>
<td>0.989 - 0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR1</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR6</td>
<td>0.999</td>
<td>0.997 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR5</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR3</td>
<td>0.999</td>
<td>0.998 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR1</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR6</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR5</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR3</td>
<td>0.999</td>
<td>0.997 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR1</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR6</td>
<td>0.999</td>
<td>0.996 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR5</td>
<td>1.000</td>
<td>0.998 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR3</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR1</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR6</td>
<td>1.000</td>
<td>0.994 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR5</td>
<td>1.000</td>
<td>0.999 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR3</td>
<td>1.000</td>
<td>0.998 - 1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR1</td>
<td>1.000</td>
<td>1.000 - 1.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
## Stratified “Z” Sector Intraclass Correlation

<table>
<thead>
<tr>
<th>Sector</th>
<th>Single Measures ICC</th>
<th>95% Confidence Interval</th>
<th>F Test</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal AP LR6</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP LR6</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR5</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR3</td>
<td>0.996</td>
<td>0.985</td>
<td>0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>AP LR1</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Distal AP UR6</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mesial AP UR6</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Palatal AP UR6</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR5</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR3</td>
<td>0.992</td>
<td>0.962</td>
<td>0.998</td>
<td>0.000</td>
</tr>
<tr>
<td>AP UR1</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR6</td>
<td>0.999</td>
<td>0.998</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR5</td>
<td>0.998</td>
<td>0.986</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR3</td>
<td>0.999</td>
<td>0.996</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO LR1</td>
<td>0.998</td>
<td>0.993</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR6</td>
<td>0.999</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR5</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR3</td>
<td>0.999</td>
<td>0.994</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>CO UR1</td>
<td>0.999</td>
<td>0.996</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR6</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR5</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR3</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC LR1</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR6</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR5</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR3</td>
<td>1.000</td>
<td>0.999</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>OC UR1</td>
<td>1.000</td>
<td>0.997</td>
<td>1.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
APPENDIX B

PYTHON SCRIPT TO EXTRACT XYZ POINTS

from xml.etree import ElementTree as ET
from math import *
import re
import os
from os.path import join

### Some Caveats: There MUST be more than 9 and less than 100 subjects. Same for Landmarks

rootDir = '/Users/TamarSardarian/Documents/OsiriX Data/CephalometriX/
landmarkDict = {}

# create .xyz file
t1File = open('/Users/TamarSardarian/Documents/xyzFiles/T1_COU.txt', 'w')
t1File.write('T1 Archform Analysis 
')
t1File.write('XYZ 
')
# create .xyz file
t2File = open('/Users/TamarSardarian/Documents/xyzFiles/T2_COU.txt', 'w')
t2File.write('T2 Archform Analysis 
')
t2File.write('XYZ 
')

# print t2File.tell()
### cursor position is at 29 at this point (where we need to insert the
### Number of landmarks Dimensionality Number of Specimens##
nbrLandmarks = 99
dimensionality = 3
nbrSpecimens = 99

headerString = ("%sL %s %sA\n" % (nbrLandmarks, dimensionality, nbrSpecimens))
t1File.write(str(headerString))
# t1File.write('\n')
t2File.write(str(headerString))
# t2File.write('\n')

# Get Landmark Data from .xml file
def getLandmarkXYZ(cephFile, subjectLabel, timeFile):
    f = open(cephFile, 'r')
    cephText = f.read()
    cephData = ET.fromstring(cephText)
landmarks = cephData.findall("LandmarkDICOMCoordinates/landmark")

timeFile.write(subjectLabel)
timeFile.write("\r\n")
i = 0
for item in landmarks:
    item.get(landmarks[i])
i = i+1
    name = str(item.find("name").text)

    name = name.replace(\',\'")
    if name[0:3] == 'COU':
        x = str(item.find("x").text)
        y = str(item.find("y").text)
        z = str(item.find("z").text)
        xyzLine = ("%s %s %s \r\n" % (x, y, z))
        #print xyzLine
        timeFile.write(xyzLine)

# Write the landmark names read from the first file encountered.
def writeLandmarkNames(cephFile, t1File, t2File):
    f = open(cephFile, 'r')
    cephText = f.read()
    cephData = ET.fromstring(cephText)

    landmarks = cephData.findall("LandmarkDICOMCoordinates/landmark")
    #nbrLandmarks = len(landmarks)

    i = 0
    nbrLandmarks = 0
    for item in landmarks:
        item.get(landmarks[i])
        name = str(item.find("name").text)
        # Get rid of the space in the landmark label
        name = name.replace(\',\'")

        if name[0:3] == 'COU':

            t1File.write(name)
            t1File.write(\'\n\'

            t2File.write(name)
            t2File.write(\'\n\'

            nbrLandmarks = nbrLandmarks+1

    t1File.write("\r\n")
    t2File.write("\r\n")
    return nbrLandmarks
count = 0
landmarkswritten = 0
for dirPath, dirNames, fileNames in os.walk(rootDir):
    for file in fileNames:
        fileExt = os.path.splitext(file)[-1]
        #print fileExt
        if (fileExt == '.xml'):
            count = count + 1
            cephFile = join(dirPath, file)

            # Get the Label of the subject from the file name
            subjectLabel = file[0:2]

            # Get the time label from the file name
            timeLabel = file[3:5]

        if landmarkswritten == 0:
            nbrLandmarks = writeLandmarkNames(cephFile, t1File, t2File)
            landmarkswritten = 1

        if (timeLabel == "T1" or timeLabel == "t2"):
            #print "T1"
            getLandmarkXYZ(cephFile, subjectLabel, t1File)
        elif (timeLabel == "T2" or timeLabel == "t2"):
            #print "T2"
            getLandmarkXYZ(cephFile, subjectLabel, t2File)
        else:
            print "We have a serious problem"
            break

        #print t1File.tell()

print "Number of files found: ", count
print "Number of Landmarks found: ", nbrLandmarks
nbrSpecimens = count/2

print t1HeaderString = ("%sL %s %sA" % (nbrLandmarks, dimensionality, nbrSpecimens))
print t1HeaderString

#open t1File
print "Congrats! The widths are measured... Now let's get this thesis done!"