THE EFFECTS OF ORTHODONTIC TREATMENT ON THE ORAL COMMISSURES IN GROWING PATIENTS

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ABSTRACT

Objective: The aim of this study was to investigate the effect of extraction and non-extraction orthodontic treatments on oral commissures.

Materials & Methods: Pre- and post-treatment 3dMD images of 47 patients aged 10-19 were studied for changes in inner and outer commissure width, philtrum height and buccal corridor width. The subjects either had extractions of all four first premolars, upper first premolars only, or were treated non-extraction. The superimposed 3dMD images were collected and qualitative and quantitative analyses were completed using 3dMD Vultus software. Interincisal angle and upper incisor to NA changes were also calculated using pre- and post-treatment lateral cephalograms. Regression analyses were applied controlling for age, gender, ethnicity, angle classification, and treatment time.

Results: While all groups showed a nominal increase in the inner and outer commissure widths from T0 to T1, only the non-extraction group revealed a statistically significant change ($p < .05$). Buccal corridor width increased in all three groups but was only statistically significant in the extraction of four first premolar extraction group ($p < .02$). Treatment type had no statistically significant influence on philtrum height and interincisal angle among the three groups. Qualitatively, the commissures exhibited variable changes regardless of treatment type but trended to exhibit more of a positive change for the extraction of upper/lower first premolar group.

Conclusion: Extraction of either all four premolars or upper premolars only does not appear to be associated with a measurable change in the commissure width. An increase in buccal corridor width was highly associated with four first premolar extractions and increased with age. Incisor inclination was strongly correlated with four first premolar extractions and resulted in a greater change in outer commissure width. Philtrum height remained relatively unchanged in all three groups accounting for age, treatment time, and gender indicating that this is a relatively stable structure during growth and shows minimal change with orthodontic treatment.

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CHAPTER 1

INTRODUCTION

Smile esthetics and smile design have always held paramount importance in orthodontic diagnosis and treatment planning. Orthodontic outcomes were traditionally assessed using lateral cephalograms to measure changes in the profile. Yet, patients tend to judge their smile esthetics outcome mostly from the frontal view. What is also important in such judgement is the structure of the commissures, their lateral extent upon smile and whether they are angled inferiorly or superiorly. The appearance of the oral commissures is significant and are heavily scrutinized in modern society. The commissure is defined as the junction of the lower and upper vermillion borders; known more commonly as the angle of the mouth. Upturned commissures give the impression of happiness and youth and are considered more esthetically pleasing. Conversely, down turned, and flat commissures typically convey sadness and aging. Because commissure shape plays heavily into smile esthetics, special attention should be given to this area. Any changes due to orthodontic treatment need to be examined and recorded accurately.

Until recently, orthodontists relied on traditional methods such as two-dimensional radiographs and photographs for diagnosis, treatment planning and outcome assessments. Unfortunately, these methods have limitations due to a high percentage of user error. It had been difficult to capture a three-dimensional representation of a patient’s face without costly equipment or exposing the patient to a greater amount of radiation. The 3dMD face system provides clinicians with a non-invasive method to measure and analyze a three-dimensional reconstruction by photographing the face from two different planes. (Kang, 2018). It results in not only linear measurements but also surface area and volumetric measurements (Hong, 2017). In less than seven seconds, this technology can accurately capture a patient's head position and multiple facial expressions as a safe and reliable alternative to other methods of three-dimensional imaging such as CT and CBCT (Hong, 2017). An important aspect of this technology is the ability to superimpose images. Once the images are superimposed, it allows the clinician to track changes in the soft tissue as treatment progresses. The face system software uses color histograms to track changes in designated landmarks.

Previous studies have used 3dMD technology to measure the effects of orthodontic treatment on soft tissue. One of the first studies done at Temple University using 3dMD superimposition technology was done by Devin Croft in 2013. The purpose of his study was to use 3dMD to assess effects of treatment and growth quantitatively and qualitatively for non-extraction, extraction and expansion procedures on the soft tissue. Croft aimed to explore whether soft tissue surface images created by 3dMD are useful in the analysis of treatment outcomes in orthodontics (Croft, 2009). Another study done by Dr. Jinah Kang in 2018 used pre- and post-treatment 3dMD images to study the effects of orthodontic treatment on the nasolabial fold in Class-I patients with four premolar extractions (Kang, 2018). Since then, no further research has been done to measure the effects of orthodontic treatment, including first premolar extraction and non-extraction, specifically on width or fullness of the commissures in growing patients. It is important for clinicians to know the effects of their treatment on the soft tissue; especially, in these highly scrutinized areas of the face to provide patients with ideal smile esthetics at the end of orthodontic treatment.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Ideals of Facial Esthetics

2.1.1 Defining Beauty

Esthetics, or the study of beauty, is associated with eliciting emotional pleasure within the limbic system, activating the reward center of the brain (Rhodes, 2005). It is said that something is not considered beautiful until an emotional response is elicited within the subconscious portion of the brain (Ricketts, 1982). The main determinant for identifying a person's attractiveness is by examining his or her face. There is a common assumption that people with attractive faces have more positive emotional qualities simply because the brain is experiencing pleasure when these individuals are faced (Kar, 2018). People who are considered beautiful are often viewed as friendlier, more intelligent, socially competent and are usually treated better than those who are not considered attractive. People generally have no difficulty identifying what is beautiful, but they often have difficulty in defining why they believe it is beautiful or what specific attributes cause it to be beautiful (Hicks, 2020). The question that has been asked for generations is what is it that makes a person attractive.

2.1.2 Determinants of Beauty

Although the concept of beauty is largely considered subjective, there are certain features that most can agree on that makes a face more attractive. There are three main features that are thought to contribute to an esthetically attractive face: bilateral symmetry (how similar both sides of the face are mathematically), sexual dimorphism (feminine traits for women and masculine traits for men) and averageness (how closely the face resembles the average face of a population) (Rhodes, 2005). One theory as to why these traits are desired is that a face that has all three of those traits demonstrated developmental stability in utero. Asymmetries and deviations from "averageness" indicate genes that were unable to overcome developmental abnormalities and are sometimes associated with syndromes; either inbreeding, premature births, or other extrinsic factors. The absence of facial symmetry seem to convey that a person's genes are less suitable for reproduction. Indeed, attractiveness is strongly tied to potential mate qualities (Hicks, 2020). Typically, the attractiveness of a face, in mathematical terms, decreases as the asymmetry becomes greater. Studies have shown that when participants are given multiple images of a face with some aspect of the face being asymmetric and those that are perfectly symmetric, the participants are more likely to choose the perfectly symmetrical face as the most attractive (Rhodes, 2005).

Additionally, sexual dimorphism plays a large role in beauty, as these features are what attract a mate. More feminine features include high cheek bones, full lips, narrow and pointed chin, and smaller noses whereas more masculine features include a square jawline and chin, thin lips, thick brows, flatter cheek bones and longer noses. There are other traits including youthfulness, a kind or friendly expression, and ability to care for oneself that also contribute to what makes a face appear attractive (Rhodes, 2005).

Even as trends and societal norms change what is considered the most esthetic face, the fundamentals of these three determinants have not changed over hundreds of years.

2.1.3 The Golden Proportion

Before scientists were conducting formal facial analyses to determine beauty, the Greek and Roman artists were attempting to use mathematics, or “The Golden Proportion” to understand facial esthetics and portray it accurately in their artwork (Kar, 2018). The Golden Proportion, also known as the “Divine Proportion” or “Fibonacci Proportion” is found when a line divided into two parts results in a long line that is divided by the small line is equal to the total length of the line divided by the long part resulting in a ratio of 1:1.618. It has been used since the time of the Egyptians and Greeks and is found frequently in early hieroglyphics of tomb walls, art, sculpture, and architecture. It is thought that objects or faces with the Golden Proportion activate the limbic system causing attraction. In 1982, in an effort to define beauty using mathematics, Ricketts utilized the Golden Proportion to measure and analyze facial esthetics from a random selection of 10 photographs from magazines using multiple races. He found that correct proportions and symmetry are essential for facial harmony, and as a result, beauty (Ricketts, 1982).

2.1.4 Application of the Golden Proportion to the Face

The basic principles of the Golden Proportion, which emerged many millennia ago, are still used today to evaluate facial esthetics. In order to determine if a particular face follows the Golden Proportion, the length and the width of the face are first measured. The Golden ratio of the face should be 1.6. indicating that the length of the face should be one and a half times longer than it is wide (Kaya, 2018). This is considered esthetically ideal. Next, the face is divided into three sections:

1) Trichion to Glabella: The hairline to the most prominent (or most anterior when viewed from the profile) part of the forehead
2) Glabella to Subnasale: The most prominent part of the forehead to the point where the inferior border of the nose meets the superior border of the upper lip
3) Subnasale to Menton: The junction of the nose and upper lip to the most inferior part of the soft tissue chin

If following the Golden Proportion, these three parts should all be equal (Kaya, 2018).

Lastly, the Golden Proportion states the length of the ear (from top of the ear to the base of the lobe) should be equal to the length of the nose (nasion to subnasale) and the width of the eye should be equal to distance between the eyes. It is very rare for a face to have perfect symmetry and a face is still considered "attractive" if it does not follow the Golden Proportion. The proportion is simply a guideline in determining if a face exhibits facial symmetry.

For many years it was considered the most esthetic to have all three parts of the face equal. Interestingly, current societal views of an esthetic face show that the lower face height for males should be 48% of total face height, and 45% of total face height for females (Kar, 2018), not following the Golden Proportion.

2.1.5 Cultural Differences in "Beauty"

It has long been discussed that esthetic preferences are cultural, rather than biological (Rhodes, 2005). It is known that children under the age of five can still identify something as “beautiful” or esthetically pleasing before they are conditioned to accept cultural standards of beauty. Studies have shown that people of different cultures often still agree on a standard of beauty, but cultural differences do play a role in attractiveness preference.

In a study done by Hall et al in 2000, profile silhouettes depicting different profile convexities, lip prominence, nasolabial prominence and mentolabial sulcus were shown to Caucasian and African American orthodontists and lay people. The study found that all participants preferred the African American profiles to have a greater convexity and more prominent upper and lower lips than the Caucasian profile (Hall, 2000). In contrast, a study done by Farrow et al in 2005, where subjects had to choose the profile they found most attractive, found that African American patients and orthodontists preferred a straighter profile than what is considered the norm for African Americans but a more convex profile than the Caucasian standards (Mejia-Maidl, 2005).

A study done by Mejia-Maidl et al found that Mexican Americans preferred less prominence of the upper and lower lips than Caucasians, particularly for females. When asked to choose the most attractive option from a selection of profile images, the subjects preferred more prominent lips in females than males (Mejia-Maidl, 2005).

2.1.6 Patient Perception of Facial Esthetics

Adult patients seeking orthodontic treatment are primarily concerned with the esthetics of their face and smile. The psychological effects of an attractive smile can improve a patient’s quality of life greatly. Yet, a patient and orthodontist may have different goals on how the final result should appear. Many times a patient is more concerned with the esthetics of their smile rather than the functionality of the occlusion. While orthodontists may look at numbers and measurements to achieve results that are within the range of normal, a patient may prefer a result that is a deviation from the norm. An example of this is a patient who wants to keep a diastema or gap between two front teeth rather than close the gap completely. Self-perception of esthetics may not always correlate with standard measurements and cephalometric values. Plethora of research has been dedicated to defining the standard of beauty in facial esthetics, but this standard cannot be held static due to the everchanging societal trends and values. It is important for orthodontists to keep up with current trends in facial esthetics, as adhering to old standards could result in an outcome that is no longer considered socially acceptable (Hall, 2000).

2.2 The Lips and Commissures

2.2.1 Anatomy of the Lips and Commissures

The lips are critical for chewing and food intake, phonation, and articulation, showing facial expressions and emotions, and for contributing to the overall esthetics of the face. The upper lip originates superiorly from the base of the nose and extends to the free edge of the vermillion border inferiorly and the nasolabial folds laterally (Kar, 2018). Similarly, the lower lip originates superiorly from the superior free vermillion border to the chelion laterally and the mandible inferiorly.

The Outer Commissures: defined as the junction of the lower and upper vermillion borders, known more commonly as the angle or corner of the mouth or landmark "chelion". Represented by the black dots in Figure 1.

Outer Intercommissure Width: the distance between the outermost junction of the vermilion borders of the lips at the corners of the mouth (right and left chelion). This is also known as the "smile width." Represented by the black dashed line in Figure 1.

Inner Intercommissure Width: the distance from the inner most corner of the mouth from right to left. Represented by the red dashed line in Figure 1.

Commissure Height: the distance from the alar base (most lateral/inferior point of the nose) to the outer commissure of the lips.

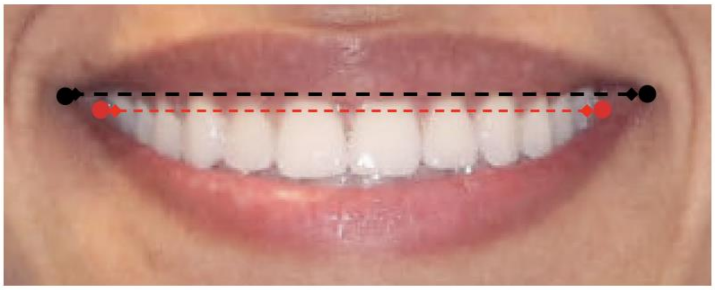

Figure 1: Anatomy of the Inner Commissure width (red dotted line) and Outer Commissure Width (black dotted line)

2.2.2 Defining the Ideal Lips

The shape and volume of an individual's lips play a large part in determining facial esthetics (Kar, 2018). According to the Golden Proportion, the ideal ratio of the upper lip to the lower lip is 1:1.6 with the height of the upper lip being less than the height of the lower lip. Additionally, in the profile view, the upper lip should project 3.5 mm ahead of a line drawn from subnasale to the most anterior part of the chin, and the lower lip should project 2.2 mm ahead of that line for ideal lip prominence. In general, females prefer more lip prominence in the profile view than males. Anthropologic studies have shown that wider and fuller lips in relation to facial width and greater vermillion height are considered more esthetic (Kar, 2018).

2.2.3 Ethnic Differences in the Lips

Although the “ideal” vertical height ratio of 1:1.6 is sometimes considered the most esthetic, the ideal ratio of the vertical height of the lips as well as prominence differs among ethnicities due to genetic differences between races. Caucasian males and females have the smallest amount of lip thickness while Chinese women have a much greater lower lip thickness leading to an increased lower lip prominence and Chinese men have the greatest overall total lip volume when compared to Caucasians (Kollipara, 2017). The most common vertical height ratio of upper lip to lower lip for Chinese women is 1:1.25, 1:1.11 for Korean women and 1:1.43 for Caucasian women (Kollipara, 2017). African American males and females tend to have a greater lip volume and thickness compared to other ethnicities and find a more prominent upper and lower lip more esthetic (Kar, 2018). In the study done by Mejia-Maidl et al, Mexican Americans preferred less protrusive upper and lower lips compared to Caucasian norms. Other studies have shown that Korean women prefer fuller lips while Japanese women prefer thinner lips (Kollipara, 2017). Ultimately, it is important for the orthodontist to pay special attention to a patient's ethnic background and individual goals when planning treatment that is going to affect the lips and profile.

2.2.4 The Aging of the Lips

As a person ages, the proportions of the lower face height changes. There is a gradual loss of collagen, elastic fibers, fat, muscle, and bone leading to the increased appearance of wrinkles and facial lines, particularly in the lower face region (Narins, 2012). In addition, the upper lip lengthens, causing the incisor display to decrease, as well as a loss of volume of the soft tissue causing the upper lip to look "thinned" out. Other changes include lip wrinkles, dropping of the oral commissures downward and "marionette lines" (lines running vertically from the mouth to the chin) and a decreased intercommissure width (Narins, 2012). These changes can come about as a result of gravity, dental changes, dentoalveolar bone loss or maxillomandibular bony resorption, most of which are the result of aging. Soft tissue loss at the commissures also causes a downward sloping appearance of the lips (Kar, 2018). In Caucasians, male and females experience similar changes in the lips due to aging, but males do not develop rhytides (fine lines around the lips) due to a thicker skin and vermillion borders. In African American populations, the thicker lip volume protects them from the common aging signs, preventing fine lines and a thinning of the upper lip and vermillion border (Kar, 2018). Environmental factors such as smoking, UV exposure, alcohol use and weight gain can also contribute to a relative "aging" of the lips. In many individuals, changes in the lower face due to aging can have negative consequences on self-confidence and self-perceived esthetics (Narins, 2012). Advances in esthetic medicine allow patients to mask or repair the effects of aging on the face with treatments such as Botox and fillers. Some patients also seek out orthodontics in an attempt to regain a youthful smile.

2.3 Evaluating Facial and Smile Esthetics

2.3.1 Smile Analysis

Analysis of the smile is a key component to any clinical exam. Many components make up the smile- including the lips, teeth, and gingiva. The smile can be analyzed in two different planes: transverse and vertical. The transverse plane of the smile includes the buccal corridor width, arch form and any cants that may be present, whereas vertical plane characteristics include how much gingival and incisor display is present upon smiling and at rest.

Buccal Corridor Width: measured from the mesial line angle of the most posterior visible tooth to the interior portion of the commissures of the lips (inner commissure) (Graber, 2012). Orthodontists attempt to eliminate excessively wide buccal corridor width and eliminate any “negative or black space” by widening the arch form in the posterior region.

Incisal Display on Smile: number of millimeters of maxillary central incisor crown display on a “true” smile. It is considered most esthetic to have 100% of the maxillary central and lateral incisors displayed upon smiling. The degree of incisor proclination can have an effect on incisal display on smile; i..e.

excessively proclined upper incisors tend to decrease incisal display while upright incisors tend to increase it.

Gingival Display on Smile: number of millimeters of gingival display present when smiling. In ideal smile esthetics, the gingival margins of the canines should coincide with the upper lip, and the gingival margin of the lateral incisors should be slightly inferior. 1-2 mm of gingival display on smiling of the maxillary incisors is ideal.

Smile Arc: the relationship of the curvature of the incisal edges of the maxillary incisors and canines to the curvature of the lower lip in the posed social smile. Ideally, orthodontists attempt to achieve a “consonant” smile arc where the curvature of the incisal edges is parallel to the curvature of the lower lip.

Components of the smile analysis are often chief complaints for patients seeking orthodontic treatment. A lot of times patients think their smile is too “narrow” or they have a “gummy” smile. This is what makes the smile analysis one of the most important steps of treatment planning.

2.3.2 Smile Analysis with Teeth at Rest

It is important to quantify resting tooth–lip relationships as well as how the dynamics of the smile interact with the maxillary teeth in order to come up with a quantified treatment plan. The following measurements should be performed on a patient whose lips are at rest (Graber et al., 2012).

Philtrum Height: Measured from subspinale (middle of the base of the nose) to the most inferior portion of the upper lip on the vermillion tip (Graber, 2012).

This measurement is important because the philtrum length increases with age. Ideal philtrum height ranges from 13-15 mm and should be equal to commissure height. Patients with a short philtrum height compared to commissure height tend to have an appearance of always frowning.

Commissure Height: The commissure height is measured from the alar base (most lateral/inferior point of the nose) to the outer commissure of the lips. Commissure height should be equal to lip length with an ideal range of 20-23 mm (Sabri, 2005).

Interlabial Gap: The distance between the upper and lower lips. If the gap between upper lip and lower lip is greater than 4 mm at rest, it is referred to as "lip incompetence."

Incisor Display at Rest: The amount of maxillary incisor showing when the patient's lips are at rest. This value decreases with age as upper lip length increases.

2.3.3 Traditional Records to Assess Smile Esthetics

An orthodontist should begin to assess a patient's facial esthetics from the moment they walk in the door. Malformation of the ears, the space between the eyes and any other marked genetic differences can be determined during the first conversation with the patient, before the clinical exam is performed. In addition to a panoramic and lateral cephalogram, digital photographs should be taken intra- and extra-orally. For proper treatment planning, four extraoral photos should be taken: 1 frontal smiling, 1 frontal at rest (with teeth in maximum intercuspation), a 45-degree oblique view and profile view.

Along with the clinical exam, the frontal smiling photograph is one of the most important photographs to perform a detailed smile analysis including smile arc, buccal corridors, gingival display, and many others. The 45-degree and profile photographs are used to assess the patient's sagittal dimension. The 45-degree photo can be used to overcome limitations of the frontal photos and assess characteristics such as incisor proclination and torque. Five intraoral photos should be taken: one frontal photograph with the camera perpendicular to the occlusal plane, two buccal photographs on the left and right side and upper and lower occlusal photographs.

2.3.4 Limitations with two-dimensional analysis

The limitations with static records such as photographs and two-dimensional radiographs of patient are that they are unable to accurately reproduce the dynamic relationship of smile esthetics.

When taking extraoral photographs of a patient, it is often difficult to have the patient present a "true" smile. Ackerman and Ackerman suggested that patients' generally have two types of smiles: the social smile and the enjoyment smile. The social smile is typically a more reserved, unstrained smile that does not show the true amount of incisor and gingival display. The enjoyment smile which is often considered a patient's "true" smile is often elicited by laughing or the smile of a patient caught off-guard. In this smile, the elevator and depressor lip muscles have maximally contracted, causing full expansion of the lips (Ackerman, 2002). Typically, when a patient is asked to smile while taking photographs, they present the social smile. Ackerman also found that patients exhibit multiple smiles when consecutive photographs are taken. It is difficult to fully assess smile esthetics if a patient is not presenting their true smile. In addition, a static photograph cannot depict the dynamic movement of a patient's smile. It is possible that incisor and gingival display could be very different on a static smile versus a smile during speech.

Historically, lateral cephalograms have been used as the primary guide in diagnosing, treatment planning and diagnosing a patient's final orthodontic outcome (occlusion and facial esthetics), with a range of cephalometric numbers that help guide tooth movement and extraction decisions (Arnett,1993). It was commonly thought that treating a patient to ideal cephalometric numbers would result in a well-balanced, esthetic face and soft tissue. However, relying on a two-dimensional image alone for treatment planning can lead to unexpected, and sometimes unfortunate changes in the soft tissue profile. Burstone stated that treating the "dental discrepancy does not always necessarily treat the facial imbalance (Arnett, 1993)." Another major source of challenges in using lateral cephalograms is the multitude of different facial analyses that exist today. Treating to one facial analysis may result in a completely different result than another. Wang et al completed a study that analyzed 10 lateral cephalograms using five different facial analyses. The study found a 60% difference in treatment plans, indicating that diagnosis based on a lateral cephalogram alone is very unreliable (Wang, 2018).

2.4 Soft Tissue Changes Due to Growth and Aging

2.4.1 Traditional Methods of Assessing Growth

Traditional longitudinal growth studies used lateral cephalograms of growing patients over a period of time to determine patterns in hard tissue growth. It was thought that the soft tissue generally follows the growth of the underlying hard tissue. Recent studies, however, have shown that this is not always the case. A study done in 2017 by Primozic et al used laser-scanning to evaluate the changes in soft tissue during growth in a longitudinal study. The authors found that pre-pubertal children show annual greater growth rates in lip prominence, most likely due to the eruption of the permanent upper incisors (Primozic, 2017).

2.4.2 Changes in the Soft Tissue Profile with Age

In the evaluation of the soft tissue profile, the lips and nose are two of the most important features. In a 1989 study, Nanda et al. found that both males and females experience an exponential increase in nose size between 7 and 8 years old and then again at 14 years old. The nose continues to grow downward and forward throughout life, unlike the majority of other facial structures (Nanda, 1989).

The upper lip grows rapidly in length from age 1 to 3, the rate of growth then decreases from age 3 to 6 years and then increases again in adolescence. Upper lip thickness reaches its peak at age 14 in females and at age 16 in males in the vermillion region. After reaching peak thickness in adolescence, the lips then begin to thin as age increases into adulthood. Individuals that were followed longitudinally in the Michigan

Growth Study revealed that in Caucasians particularly, the upper lip lengthened by an average of 3.2 mm and thinned 3.6 mm between adolescence and mid-adulthood and an additional average mean lengthening and thinning of 1.4 mm into adulthood (Proffit, 2006). Once full growth has been attained, it has been observed that there is a significant increase in lip length but a decrease in volume of the lips. The decrease in the height of the vermillion border is most likely due to thinning of the vermillion border thickness, resulting in an inversion of the lip. MRI studies to analyze aging lips have shown that it is not volume loss causing an increase in lip length but rather a redistribution of the volume from thickness to length (Iblhe, 2008). There is no change in overall total volume of the lips (Sharma, 2014). With increasing age, the lip width increases, lip height decreases, and the outer commissures tend to angle inferiorly.

The philtrum height increases concurrently with the growth of the midface maxilla since the upper lip tends to follow growth of the maxilla. Philtrum length shows a significant increase associated with the adolescent growth spurt that halts with the completed growth of the midface, a slight decrease in length in the third decade of life and then a gradual increase again as the upper lip height decreases (Vig, 2000).

2.4.3 Assessing the Growth of the Soft Tissue

Orthodontic treatment is performed on children and adolescents frequently. Since soft tissue esthetics are essential to consider in orthodontic treatment planning, several studies of facial profile changes during growth have been performed. However, these investigations used only two-dimensional lateral cephalograms for analysis. The limitations of this method are the increased radiation exposure and inability to examine the soft tissue from a frontal or three-quarter view. Lateral cephalogram superimpositions are still the gold standard for determining hard tissue growth changes, but no method exists currently as the gold standard to determine soft tissue changes due to growth. New, non-invasive techniques that evaluate the soft tissue in three dimensions will be essential in determining soft tissue changes during growth as well as determining if orthodontics influences those changes.

2.5 New Techniques in Facial Analysis

2.5.1 Introduction to Three-Dimensional Imaging

With increasing demand for esthetic medicine, patients are now more aware of their personal facial appearance and the expectations for esthetic treatment are much higher. Three-dimensional approaches to analysis of facial esthetics are quickly replacing two-dimensional methods (Narins, 2012) due to the increased detail and accuracy they provide. Whereas a two-dimensional image consists of two coordinates: an x-axis (horizontal) and a y-axis (vertical), three-dimensional images include an additional coordinate, the z-axis (depth). Three-dimensional objects are generated through a series of steps. The first step is referred to as “modeling” or “texture mapping.” The image is created by adding layers of pixels to a wire mesh frame in the form of triangles or polygons. Texture and lightening are then added to the image before the image is “rendered.” During the rendering process, the computer software converts the layered pixels in the wire mesh frame into a realistic image projected onto a two-dimensional computer screen (Hajeer, 2004).

2.5.2 3D Imaging using CBCT

The introduction of craniofacial CBCT in 2001 allowed orthodontists to capture valuable information about a patient's hard and soft tissues. Regrettably, at the time they were expensive pieces of equipment. Also, this technology exposes the patient to a large dose of radiation. With today's low radiation machines, it is considered a nonissue. Nonetheless, it is advised ALARA principle is adhered (Erten, 2018). CBCTs are useful for patients with significant craniofacial deformities or patients with complex treatment outcome needs but are not necessary for every orthodontic patient. In three-dimensional medical imaging, anatomical data points are collected, processed by specific computer software, and then displayed to give the illusion of depth (Hajeer, 2004). Technology systems exist in which the orthodontist can send a patient's records (including a CBCT and 3D laser scan) to a third-party company which creates a three-dimensional rendering of the face or three-dimensional digital study models and send them back to the orthodontist. However, this is time consuming, expensive and does not provide a good indication of the soft tissues. More recently, frontal or profile views can be extracted from the CBCT and converted to DICOM (Digital Imaging and Communications in Medicine) files and uploaded so the transparency of the hard and soft tissue can be altered and analyzed. This method is primarily used to gain information about root inclinations, amount of bone present and for the location of impacted cuspids.

2.5.3 Photogrammetry

Photogrammetry is defined as "the art, science and technology of obtaining reliable information about physical objects through processes of recording, measuring and interpreting photographic images" (Chadwick, 1992). In orthodontics, this process allows a clinician to obtain facial measurements and proportions from clinical photographs. Image acquisition is done using a metric camera (where the focal length and internal dimensions are exactly known and can be calibrated). Photographic plates, instead of film, are used to capture the images in order to ensure a flat image capture and avoid any distortion. A stereopair of images is obtained and the two images are quantitatively analyzed (Chadwick, 1992). The advantages of using this method are that it avoids a device or instrument in the patient's mouth that could cause soft tissue distortion and it provides no risk or harm to the patient. This method has a high level of patient comfort since all measurements could be done hours to days after the images were taken. The downside to this method was that it was highly operator sensitive and required a complicated optical device to view the images stereoscopically. The face is a highly complicated structure with too much detail that photogrammetry is unable to capture accurately.

2.5.4 Stereophotogrammetry

The concept of stereophotogrammetry is based on photographing a subject and combining stereophotos taken from two different directions by a pair of configured cameras to create a three-dimensional surface contour map of the face. The two cameras should be mounted on a frame separated by 50 cm, positioned convergently with an angle of 15 degrees (Hajeer, 2004). The specific positioning of the dual cameras allows them to capture a 180-degree view of the patient without needing to rotate them and capture another image. The result is a life-like color rendering that can be analyzed three-dimensionally on a two-dimensional computer screen. This method has many advantages (Erten, 2018):

1. Non-invasive, no-contact technique with no radiation exposure
2. Short acquisition time, reducing the risk of patient movement
3. Can be combined with CBCTs
4. 3D images can be rotated and viewed from any direction (useful for surgical planning or patients with craniofacial anomalies
5. 3D images are stored digitally
6. Very efficient in capturing facial morphology and soft tissue changes

Once the three-dimensional image has been reconstructed and displayed, the clinician can analyze and calculate measurements on the model. This method has become increasingly more popular due to the decreased cost of the clinical set-up and software (Heike, 2010). The advent of such technology to assess multiple views from one image provides clinicians with the ability to not only evaluate the soft tissue for esthetics and orthodontic treatment, but to also evaluate soft tissue changes after orthognathic surgery, facial asymmetries, evaluation of craniofacial abnormalities and to track skeletal/facial growth in child and adolescent patients (Nuveen, 1996).

2.5.5 3dMDface Software

In an effort to provide a more efficient method of capturing three-dimensional images of a patient’s face, the 3dMD software was introduced. Whereas most three-dimensional scanning technology was used to scan inanimate objects, the 3dMD software uses highly advance motion 3D/4D capture technology to capture images of human faces with incredible precision. This method uses a combination of stereophotogrammetry and structure light to produce a three-dimensional rendering of a patient's face. Similar to stereophotogrammetry, 3dMD captures a 180-degree view of the patient but in only 1.5 milliseconds. The faster acquisition time reduces the amount of patient movement in the image, thereby decreasing artifact in the final image. The 3dMD face software is widely recognized for its precision, with a geometry accuracy of 0.2 mm root mean square (Aynechi, 2011).

2.6 Soft Tissue Changes with Orthodontics

2.6.1 Treatment Planning

Although it is widely accepted that orthodontic tooth movement can alter facial esthetics, most of the time orthodontists are mainly concerned with correcting a patient's malocclusion. A large amount of time and effort is dedicated to treatment planning and treating the transverse, vertical and sagittal components of a patient's bite. The treatment planning of facial esthetics along with bite correction is much harder to accomplish. Some argue that when orthodontics is carried out to obtain ideal occlusion, ideal facial esthetics will result (Arnett, 1993). However, this is not always the case. It is common that the ideal treatment mechanics for correcting a patient's malocclusion do not always coincide with what is best for the patient's facial esthetics. An example of this is a patient with very little incisal display on smiling with a deep bite. Intruding the maxillary incisors would help to correct the deep bite but worsen the facial esthetics. If orthodontists are only concerned with aligning the teeth and correcting the occlusion, a decline in the facial balance could occur.

2.6.2 Esthetic Changes with Extractions

When determining whether to incorporate extractions as part of orthodontic treatment, the facial esthetics must also be considered. It is often observed that extracting teeth (particularly first premolars) will decrease the prominence of the lips and overall fullness of the profile. A patient with very full lips and a convex profile will look more esthetic with upper and lower first premolar extractions than a patient with a straight or concave profile and decreased lip thickness (Graber, 2012). If the orthodontist has decided to treat the patient non-extraction, then special consideration must be paid to the pre-treatment position of the upper and lower incisors. If the incisors are proclined or protruded excessively so that it affects the ability of the lips to close at rest, then extracting teeth and retracting the incisors would be a better esthetic option for that patient (Graber, 2012). Although there is literature showing a correlation between extractions and decreased lip prominence and profile changes, no studies outside of Temple University have been done using three-dimensional imaging to show the changes in smile width or volumetric changes of the commissures specifically. Since smile analysis is a key part of treatment planning, it is important to know how orthodontic treatment effects these features.

2.6.4 Soft Tissue changes shown by 3dMD

Several master's thesis studies at Temple University have utilized 3dMD technology to analyze the effects of orthodontic treatment on the soft tissue. Croft et al. was the first to use superimposition of 3dMDs to measure volumetric soft tissue changes in fifteen subjects. The aim of this study was to assess the ability of the 3dMD technology to accurately analyze changes in the soft tissues as a result of orthodontic treatment and its viability as a predictor of soft tissue changes (Croft, 2009). This pilot study paved the way for future thesis studies to use the pre- and post-treatment 3dMD images in analyzing changes in specific landmarks. In 2018, Kang et al performed a study using the same superimposition technique as Croft, using 3dMD images to look at changes in the nasolabial angle in 10 patients who had extraction of four first premolars. The results of the study showed no significant cause-and-effect relationship between first premolar extractions and deepening of the nasolabial fold and unpredictable changes in the commissures (Kang, 2018). Both of these studies had very small sample sizes (15 and 10 respectively). The present study aimed to study changes in the commissures due to orthodontic treatment using a greater sample size.

CHAPTER 3

AIMS OF THE INVESTIGATION

The specific aim of this study was to use pre- and post-treatment 3dMD images and lateral cephalograms of growing patients treated at Temple University, Kornberg School of Dentistry, Podray Orthodontic Clinic to investigate the effects of orthodontic treatment (extraction versus non-extraction) on the oral commissures.

- Aim 1: Evaluate changes in the commissures and buccal corridors as a result of orthodontic treatment (extraction versus non-extraction) using pre- and post-treatment 3dMD images quantitatively and qualitatively.
- Aim 2: Evaluate changes in incisor proclination and its effect on the commissures as a result of orthodontic treatment (extraction versus non-extraction) using pre- and post-treatment lateral cephalograms.

CHAPTER 4

MATERIALS & METHODS

4.1 Facilities and Equipment

3dMD Face system and Software® and Dolphin Imaging software located in the Podray Orthodontic Clinic at the Temple University, Maurice H. Kornberg School of Dentistry in Philadelphia, PA, were used for this study. All patients receiving orthodontic treatment receive intra- and extra photos pre- during and post-treatment as well as a pre- and post-treatment 3dMD scan and lateral cephalogram. The 3dMD Face system is a stereo-photogrammetric system allowing us to capture 3D soft tissue images and superimpose them for qualitative and quantitative analysis of the soft tissue. The Dolphin Imaging software program was used to select patients based on intraoral images, extraoral images, age and race of the patients as well as evaluate pre-treatment and final lateral cephalograms of the selected patients.

4.2 Study Sample

The research proposal was submitted to the Temple University Institutional Review Board (IRB) and deemed exempt. Pre- and post-treatment 3dMD images of 47 patients who have completed treatment at Temple University, Podray Orthodontic Clinic were studied for changes in the commissures. The sample consisted of 47 randomly selected male and female patients with the following inclusion characteristics:

- Initial and final 3dMD images (.tsb files) available
- Initial and final lateral cephalogram available

- Were between the age of 10-19 years old when orthodontic treatment was initiated
- Four ethnicities: Asian, Caucasian, Hispanic and African American (as reported by the patient on initial clinic intake form)
- Patients that either had extraction of upper and lower first premolars, upper first premolars only or were treated non-extraction
- Completion of orthodontic treatment by July 1st, 2020

The final study sample included 28 females and 19 males with an average age of 12.74 years.

Subjects were separated into three groups:

Group 1: Patient treated non-extraction

Group 2: Patients treated with extractions of upper and lower first premolars

Group 3: Patients treated with extraction of upper first premolars only

Subject groups can be viewed in Table 1.

Table 1: Subject Groups and Demographics

Group number	*Group description*	*n*	*Gender Distribution %*	*Pre-treatment Age*
Group 1	Non-extraction	22	Males, 27.2, females, 72.7	12.0
Group 2	Ext U/L4s	17	Males, 41.1, females, 58.8	13.6
Group 3	Ext U4s only	8	Males, 87.5, females, 12.5	12.9

4.3 Exclusion Criteria

Patients were excluded from the study based on the following criteria

- Completion of previous orthodontic treatment

- Less than 10 years of age or more than 20 years of age

- No initial and/or final 3dMD file available

- No initial and/or final lateral cephalogram available or poor-quality image unable to be traced/superimposed

- Received orthognathic surgery as part of their comprehensive orthodontic treatment

- Patients with craniofacial deformities or syndromes

4.4 Image Acquisition

Each patient treated at the Temple University, Podray Orthodontic Clinic has a pre- and post-orthodontic treatment lateral cephalogram and 3dMD image taken as part of the initial records appointment. The lateral cephalograms are taken in natural head position and two 3dMD images are captured: one in natural head position with lips at rest and a second image with the patient smiling. All lateral cephalograms are saved in the Dolphin Imaging software and all 3dMD images are saved in the 3dMD Vultus software on one central computer located in the clinic. The 3dMD Vultus software was used to determine quantitative measurements of initial and final 3dMD images as well as superimpose the images for the qualitative analysis.

4.5 Cephalometric Analysis

Cephalometric Analysis was done using the Dolphin Imaging Software to measure hard tissue and soft tissue changes on a two-dimensional radiograph. For this study, the measurements that were compared between pre and post treatment lateral cephalograms were the Interincisal angle and the angle of the Maxillary Incisor to the line from Nasion to A-point (U1-NA) which describes the axial inclination of the upper incisors relative to A-point.

4.6 Error Analysis

All superimpositions and measurements were completed by one investigator. Five of the superimpositions were registered and superimposed three separate times and RMS value compared to ensure repeatability.

4.7 Quantitative Analysis

All 3dMD images were saved as .tsb files on a secure Windows operating system and images were superimposed using 3dMDvultus software (3dMD, Atlanta, GA). The pre- (T0) and post-treatment (T1) 3dMD images were uploaded to the 3dMD Vultus software for analysis. Changes in 4 variables were measured: 1) Outer intercommissure width (smile width), 2) inner intercommissure width (the distance between the right and left inner commissure), 3) buccal corridor space and 4) philtrum height. All measurements were done by using the Freehand Point tool and selecting the right and left inner and outer commissure points, five points along the upper lip and lower lip following the vermillion border, the midpoint between the contact point of the upper and lower lips and the most posterior visible maxillary tooth on the right and left sides. Example of point placement is shown in Figure 2. A horizontal line was computed from the right and left inner intercommissure points to measure the inner intercommissure width (ICW) and similarly for the outer intercommissure width (OCW) in mm for initial and final 3dMD images. Buccal corridor width (BC) was determined by measuring the distance between the mesial line angle of maxillary first premolar and the inner commissure on the right and left sides. Once the right and left sides were calculated, the average between the two values was taken as measurement BC_{Avg} for each subject. Philtrum Height (PH) was calculated by placing points at subspinale (middle of the base of the nose) and the most inferior portion of the upper lip on the vermillion tip and calculating the distance between the two points. All measurements for initial and final 3dMD images were recorded in an excel spreadsheet for each subject according to their treatment group and all subjects were labeled randomly 1-47. The initial and final lateral cephalograms were also superimposed to measure 2 additional variables: 1) The angular (degree) changes in the interincisal angle (U1-L1) and 2) maxillary incisor to the line from Nasion to A-point (U1-NA) using Dolphin software. The mean change and standard deviation between the pre- and post-treatment images were calculated and recorded in a spreadsheet for all 6 variables.

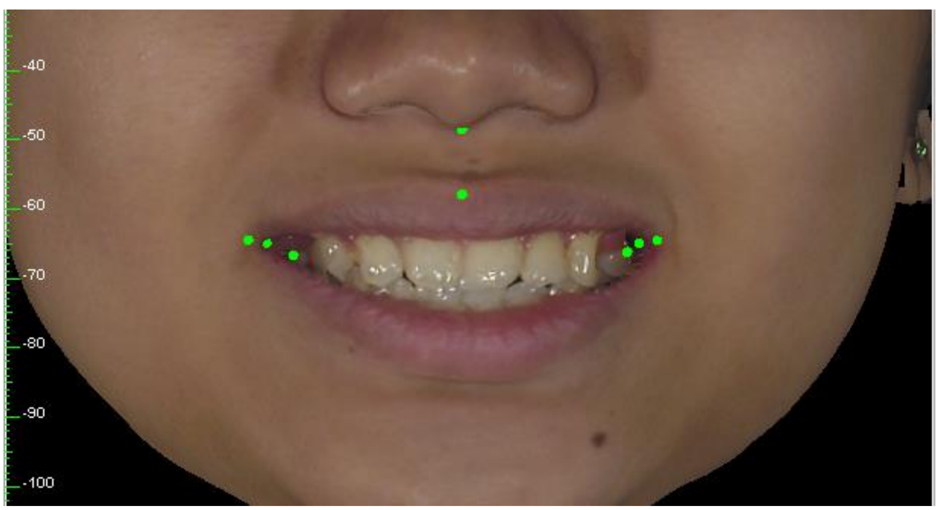

Figure 2: Example of Point Placement Using Freehand Tool on 3dMD Vultus

4.8 Qualitative Analysis

The 3dMDVultus software creates a color histogram from the superimposed images to show soft tissue changes as a result of orthodontic treatment. All pre- and post-treatment 3dMD images were oriented so that the Frankfort Horizontal plane was parallel to true horizontal. From the quantitative analysis, it was determined that the philtrum area was the most stable. This area was used to register the images to accurately superimpose the pre- and post-treatment 3dMD images. A color-coded map was generated from each superimposition and used to determine the direction and magnitude of changes in the soft tissues of the inner and outer right and left commissures and the philtrum. The histogram map consists of a color spectrum from green to red in which purple, pink and red represent a positive change of the soft tissue (more anterior movement) and green and blue represent negative changes of the soft tissue (posterior movement) as seen in Figure 3. The color changes are determined relative to the pre-treatment image. All color histograms were analyzed for surface changes to identify patterns in the soft tissue areas of the commissures and philtrum height. The images were analyzed from a frontal smiling view only and studied for patterns to evaluate trends. The data from the qualitative analysis was color coded in a table for each structure and subject, with red indicating anterior movement, green indicating posterior movement and blue indicating little to no movement (Appendix C).

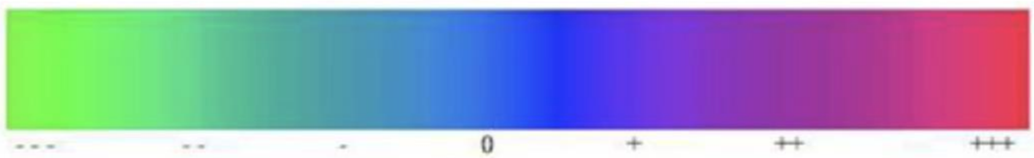

Figure 3: Color Histogram Map

4.9 Statistical Analysis

The mean and standard deviation were calculated for the difference from T0 to T1 for each variable and two-tailed T-tests and ANOVA were run to compare differences across the treatment groups. Differences with a $P < .05$ were considered statistically significant. Regression analysis was completed to control for age, gender, ethnicity, and treatment time.

CHAPTER 5

RESULTS

5.1 Quantitative Analysis

All three treatment groups showed a nominal increase in inner and outer commissure width from T0 to T1, with Group 3 showing the largest mean difference of 3.75 ± 5.54 mm for inner commissure width and 4.08 ± 5.36 mm for outer commissure width, but only Group 1 demonstrated a statistically significant change for both measurements (p = .037 and p = .025). Group 2 showed a significant increase in buccal corridor width and U1-NA measurements but a significant decrease in interincisal angle. Group 3 showed a significant increase for interincisal angle and significant decrease for U1-NA. Buccal corridor width increased in all three groups but was only statistically significant in Group 2 with a mean difference of .992 ± 1.58 mm (p = .020) . Philtrum height increased in Groups 2 and 3 (both extraction groups) but decreased in Group 1 by .125 ± 1.66 mm . None of the treatment groups showed a significant difference in this value, indicating that treatment type may have no statistically significant influence on philtrum height. Interincisal angle had the most change in Group 2 (12.41 ± 12.89 mm) and Group 3 (8.58 ± 9.77 mm), decreasing in both groups whereas it increased slightly in Group 1 by 3.39 ± 14 mm. This change was statistically significant for all three treatment groups (p = .047, p = .002 and p = .042). The mean, standard deviation, standard error, and significance values (p) for each treatment group can be seen in Tables 2,3, and 4. Differences with a P < .05 were considered statistically significant and are highlighted in yellow.

Table 2: Mean Differences and Standard Deviation for Treatment Group 1 (Non-extraction)					
Pair	Mean Difference	Std. Deviation	Std. Error Mean	t	Two-Sided p
Δ ICW	-2.06	4.33	.92408	-2.233	.037**
Δ OCW	-2.10	4.10	.87484	-2.409	.025**
Δ BC_{avg}	-.008	1.18	.25330	-.034	.973
Δ PH	.120	1.65	.35336	.354	.727
Δ IA	5.05	11.20	2.3880	2.115	.047**
Δ U1-NA	-1.0	7.31	1.5589	-.647	.524

Table 3: Mean Differences and Standard Deviation for Treatment Group 2 (Extraction of upper and lower first premolars)					
Pair	Mean Difference	Std. Deviation	Std. Error Mean	t	Two-Sided p
Δ ICW	-.215	4.86	1.178	-.183	.857
Δ OCW	-1.46	5.36	1.300	-1.13	.277
Δ BC_{avg}	-.992	1.58	.384	-2.59	.020**
Δ PH	-1.18	2.47	.601	-1.97	.067
Δ IA	-12.42	12.89	3.22	-3.85	.002**
Δ U1-NA	-.215	4.86	3.05	3.864	.002**

Table 4: Mean Differences and Standard Deviation for Treatment Group 3 (Extraction of Upper first premolars only)					
Pair	Mean Difference	Std. Deviation	Std. Error Mean	t	Two-Sided p
Δ ICW	-3.75	5.54	1.959	-1.92	.097
Δ OCW	-4.08	5.36	1.896	-2.15	.068
Δ BC_{avg}	-.46	1.48	.524	-.882	.407
Δ PH	-.434	1.73	.615	-.705	.503
Δ IA	-8.59	9.77	3.46	-2.48	.042**
Δ U1-NA	7.65	7.36	2.60	2.94	.022**

ANOVA analysis revealed there was no significant difference among the three treatment groups for OCW, ICW, BC_{avg} and PH but there was a significant different among the three groups for U1-NA and interincisal angle. Additional post-hoc tests demonstrated that there was a significant difference for IA for Group 1 compared to Group 2 and Group 1 compared to Group 3 but not for Group 2 compared to Group 3. The post-hoc test also demonstrated a significant difference for U1-NA when comparing Group 1 to Group 2. When determining whether changes in IA and U1-NA had a significant effect on OCW, ICW, BC_{avg} and PH, it was found that both U1-NA and IA had a significant effect on the OCW for Group 2 only (R2 = .55, p = .027, R2 = -.635, P = .008).

5.2. Qualitative Analysis

The color histograms for each subject's superimposition were analyzed according to the color chart shown in Figure 2. For Group 1, 42%, 57%, 48%, 19%, and 33% of the subjects saw no changes in philtrum, left outer commissure, right outer commissure, left inner commissure and right inner commissure, respectively (shown in Figure 4). The philtrum, left outer commissure, and left inner commissure showed almost an equal percentage of subjects with anterior and posterior changes, while right outer commissure and right inner commissure trended more towards a positive change. For Group 2, 29%, 47%, 59%, 18%, and 47% of subjects saw no changes in philtrum, left outer commissure, right outer commissure, left inner commissure and left outer commissure, respectively (shown in Figure 5). All subjects showed a trend towards anterior changes for all five variables. For Group 3, 38%, 38%, 50%, 38%, 50% showed no change in philtrum, left outer commissure, right outer commissure, left inner commissure and left outer commissure, respectively (shown in Figure 6). All five variables showed almost an equal percentage of subjects with anterior and posterior changes. Examples of superimpositions and histograms for three example subjects from each treatment group can be seen in Figures 6, 7, and 8.

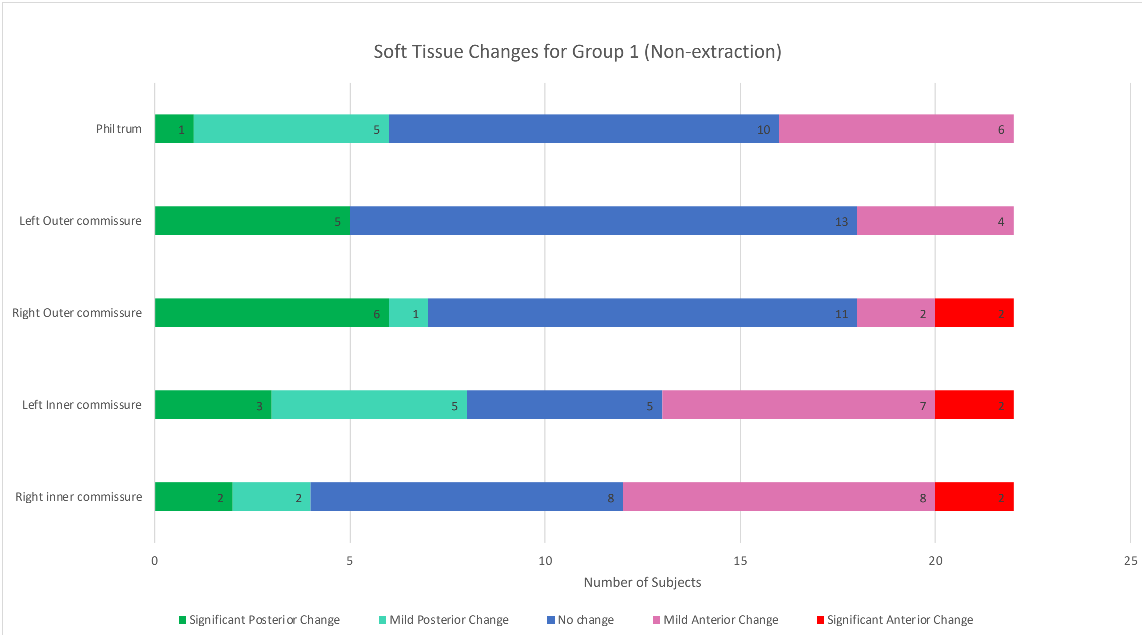

Figure 4: Soft Tissue Changes for Group 1 (Non-Extraction)

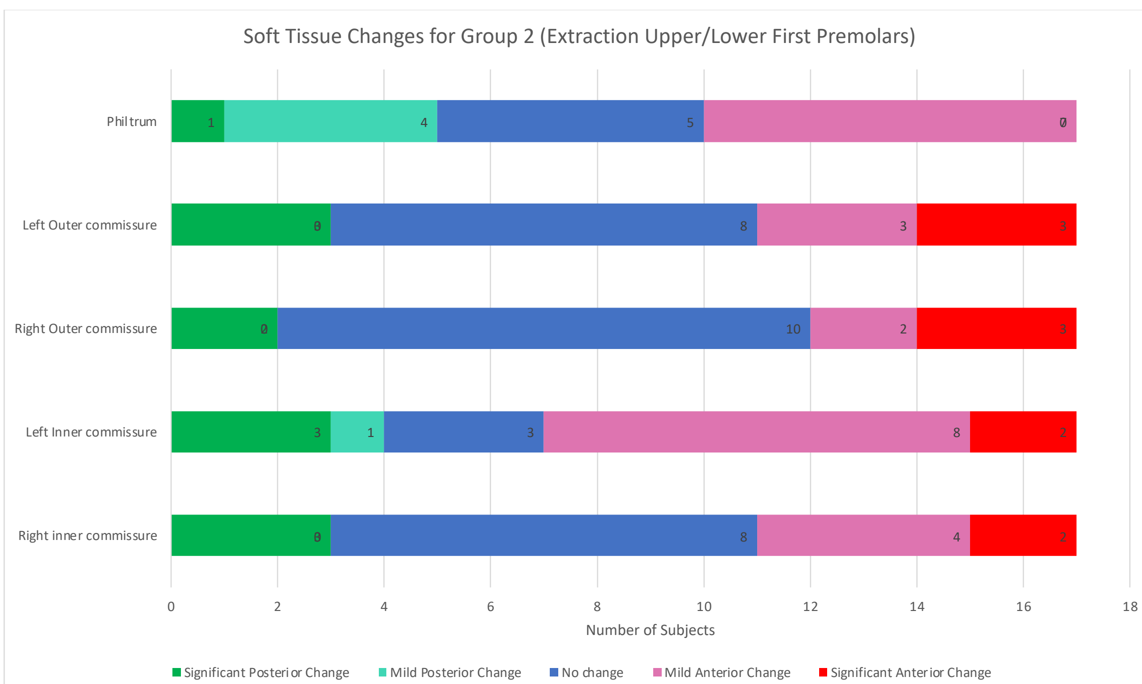

Figure 5: Soft Tissue Changes for Group 2 (Ext Upper/Lower First Premolars

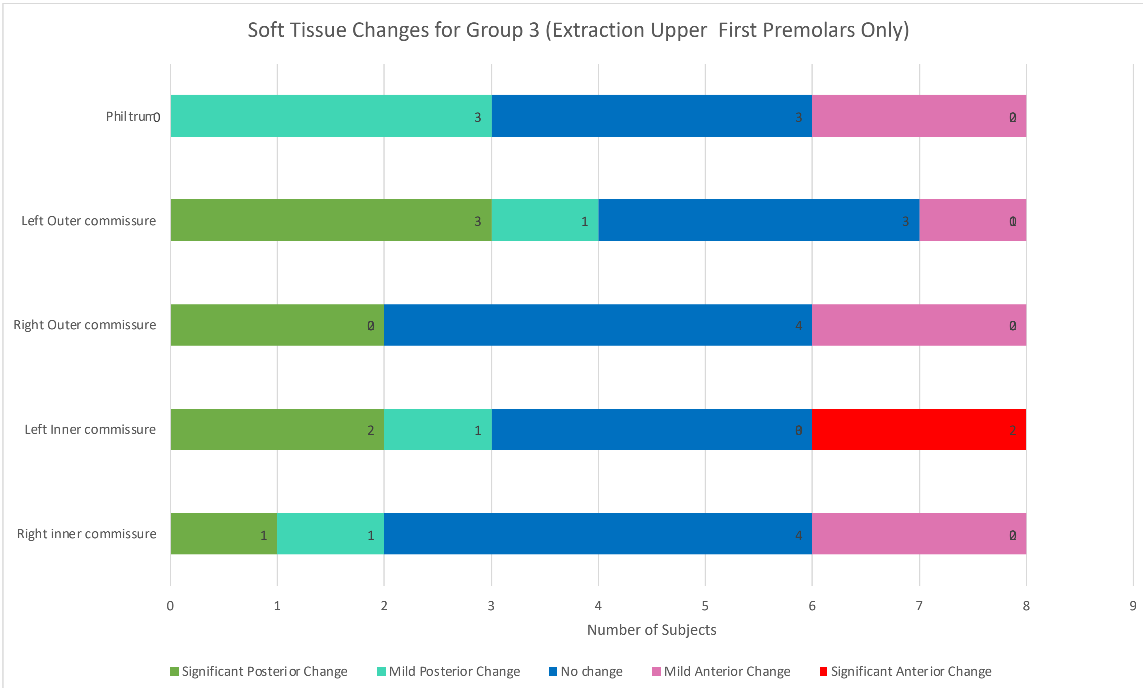

Figure 6: Soft Tissue Changes for Group 3 (Ext Upper First Premolars Only)

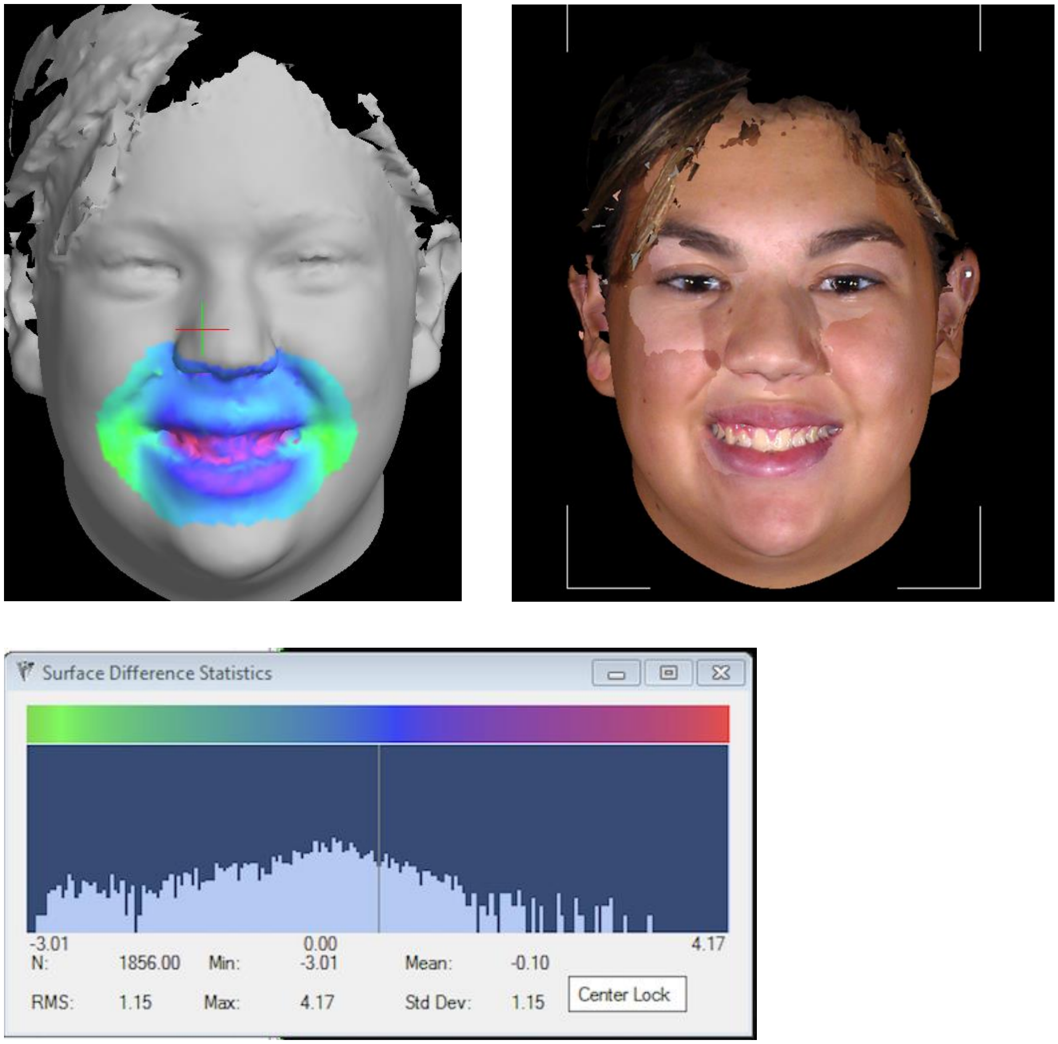

Figure 7: **Example Non-extraction Subject #15 Color Histogram of the Mouth and Superimposition**: Both the right and left inner and outer commissures showed posterior change (green) while the philtrum showed little to no change (blue).

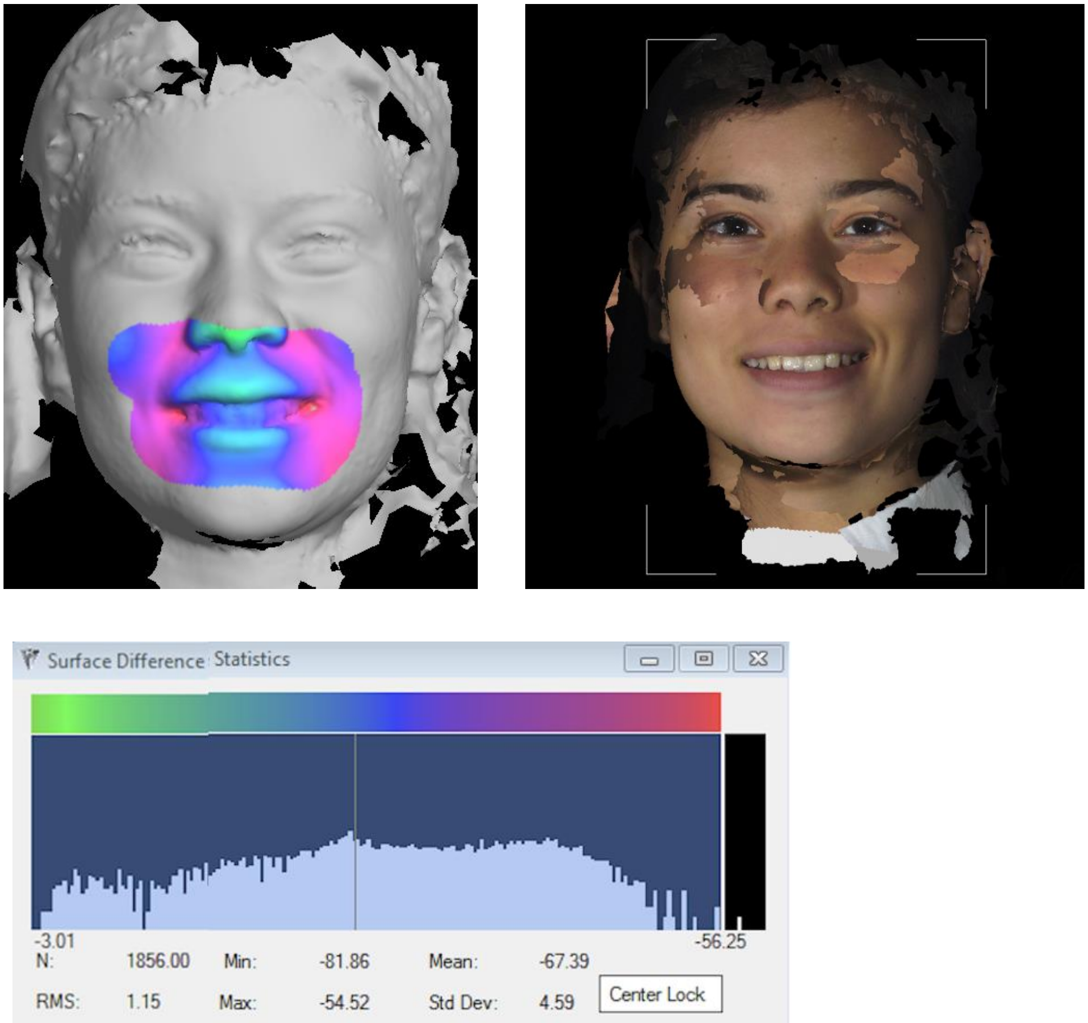

Figure 8: Example Extraction of Upper and Lower First Premolars Subject #38 Color Histogram of the Mouth and Superimposition: Both the right and left inner and outer commissures showed anterior change (red) while the philtrum showed little to slight posterior change (blue/green).

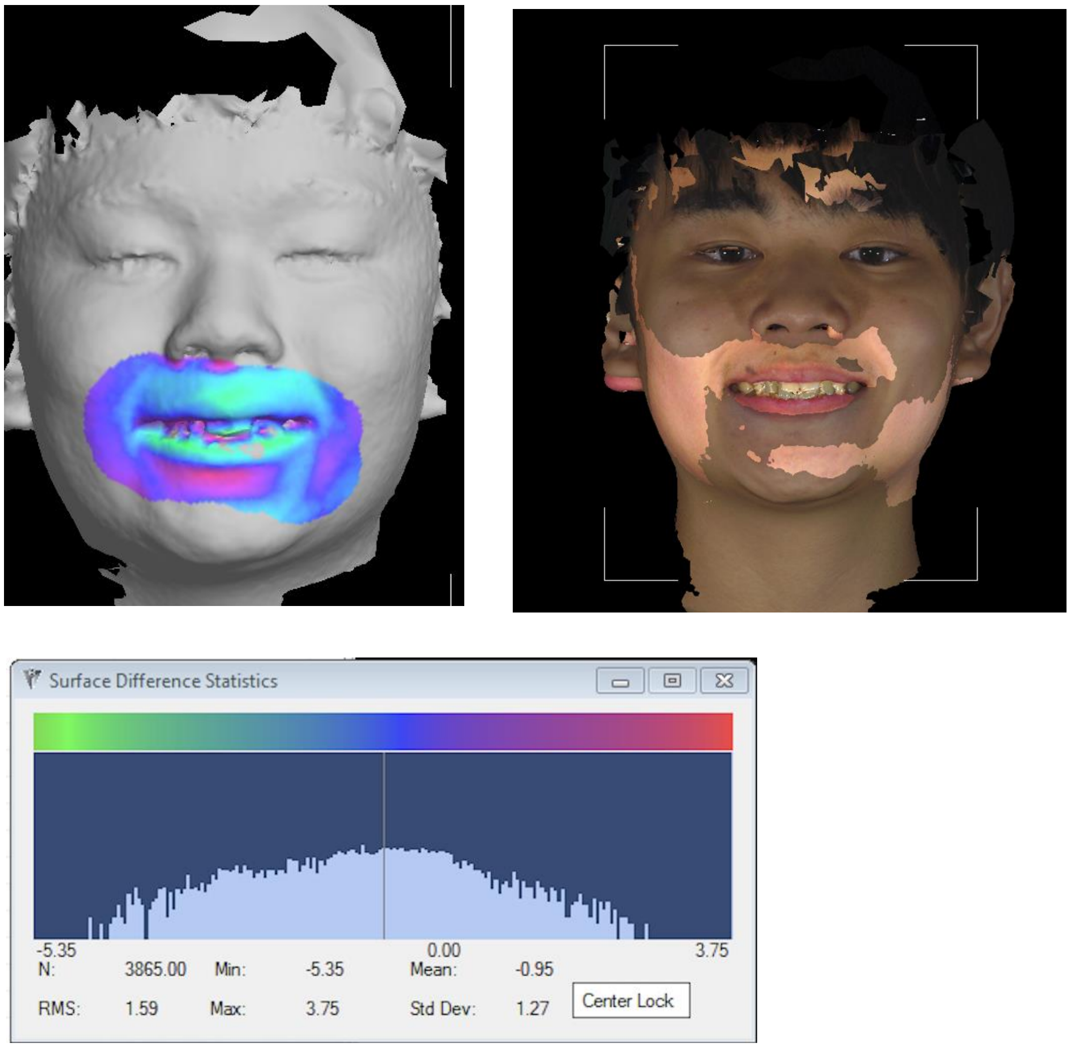

Figure 9: Example Extraction of Upper First Premolars Only Subject #39 Color Histogram of the Mouth and Superimposition: Both the right and left inner and outer commissures showed little to no change (blue) while the philtrum showed a posterior change (green).

5.3 Regression Analysis

A regression model predicting differences in ICW, OCW, BC_{avg}, PH, IA and U1-NA as the dependent variables was fit comparing the non-extraction group to the extraction of upper and lower first premolar group and the extraction of upper first premolars only using age, sex, race, treatment time and Angle's classification as possible predictors. A second regression model was also run using the same predictors but using the extraction of upper and lower first premolar group as the constant variable. The results of the two regression models can be found in Figures 5 and 6.

The first regression model for the dependent variable ICW was found not significant (p = .446, adjusted R^2 = .003). The regression model predicting difference in OCW was also found not significant (p = .241, adjusted R^2 = .068). The model predicting differences in BC_{avg} was found to be significant (p = .030, adjusted R^2 = .219) and found that for every year increase in age, the BC_{avg} increased by .32 mm and compared to the non-extraction group and that extraction of upper and lower first premolars reduced BC_{avg} by 1.47 mm. This indicates that age is a significant positive predictor for BC_{avg} and extraction of upper and lower first molars is a negative predictor for $BC_{avg.}$ The regression model predicting difference in PH using the same variables was found not significant (p = .490, adjusted R^2 = -.009). The model predicting differences in IA was found significant (p = .003, adjusted R^2 = .341) for age and the extraction of upper and lower first premolars indicating that there is a significant negative correlation between age and extraction of upper and lower first premolars for IA. The model predicting differences in U1-NA was found significant (p = .021, adjusted R^2 = .4) with regards to extraction of upper and lower first premolars only indicating that there exists a positive correlation between extraction of upper and lower first premolars and U1-NA.

The second regression model yielded very similar results with the only difference being the model predicting the differences in IA was not significant. Non-extraction treatment and age were significant predictors for changes in BC_{avg}. Non-extraction treatment was also a significant predictor for differences in U1-NA.

Table 5: Regression Model 1 Summary				
Predictors: (Constant), Ext U4s only, Ext U/L4s, Age, Race, Treatment Time, Sex, Angle Classification				
Dependent Variable	**R**	**R Square**	**Adjusted R Square**	**P-value**
ICW Diff	.450	.202	.003	.446
OCW Diff	.504	.254	.068	.241
BC_{avg} Diff	.612	.375	.219	.030**
PH Diff	.439	.193	-.009	.490
IA Diff	.690	.476	.341	.003**
U1-NA Diff	.633[a]	.400	.246	.021**
Significant predictors for BC_{avg} diff were age (p = .004) and Ext U/L4s (p = .008) Significant predictors for IA diff were age (p = .029) and Ext U/L4s (p.= .036) Significant predictors for U1-NA diff was Ext U/L4s (p = .047)				

Table 6: Regression Model 2 Summary				
Predictors: (Constant), Ext U4s only, Non-extraction, Age, Race, Treatment Time, Sex, Angle Classification				
Dependent Variable	**R**	**R Square**	**Adjusted R Square**	**P-value**
ICW Diff	.450	.202	.003	.446
OCW Diff	.504	.254	.068	.241
BC_{avg} Diff	.612	.375	.219	.030**
PH Diff	.439	.193	-.009	.490
IA Diff	.536	.287	.109	.149
U1-NA Diff	.633	.400	.246	.021**
Significant predictors for BC_{avg} diff were age (p = .004) and non-extraction treatment (p = .008) Significant predictors for U1-NA diff was non-extraction treatment (p = .047)				

CHAPTER 6

DISCUSSION

6.1 Results in Comparison to Current Literature

Previous studies using 3dMD images to detect soft tissue changes as a result of orthodontic treatment have had varying results. In the pilot study done at Temple University involving 3dMD images by Croft et al in 2009, it was found that orthodontic treatment with use of a palatal expander had a large effect on the oral commissures. However, Croft's study used an older version of 3dMD image processing software. 3dMD Vultus software, which was launched after 2009, was found to have better coordinate recognition and viewing software improves the accuracy of landmark placement. Using a similar study design to Croft but with the newer 3dMD Vultus software, in 2013 Papasikos et al. found that changes in the commissures were unpredictable regardless of treatment type. Similarly, Kang et al in 2018 found that changes in the commissures with four first premolar extractions had confounding results and necessitated future studies due to the small sample size (n=14). Due to the varying results of these studies, more research was needed to determine how orthodontic treatment is affecting one of the most prominent structures of the face. Most studies that aim to evaluate soft tissue changes, including the lips, are done from the profile view on a two-dimensional photograph or lateral cephalograms. This study aimed to focus on changes in the commissures from the frontal view with a patient smiling to determine how orthodontic treatment affects the width of the commissures and buccal corridor space to be able to predict these changes in patients more accurately. Using three-dimensional images allows for more accurate placement of anatomic points since the image can be rotated 180 degrees and more surface contours are present and can be easily viewed.

6.2 Analysis of inner and outer commissure width

The quantitative analysis of this study revealed that inner and outer commissure width and buccal corridor width increased regardless of treatment type with the extraction of upper and lower first premolar group having the largest mean change for both inner and outer commissure width. Interestingly, only the non-extraction group revealed statistically significant results for inner and outer commissure width changes. A study done by Chong et al. in 2021 that aimed to reveal age-related changes of the lips in Asian women aged 20-60 using stereophotogrammetry, found that lip width (outer commissure width) significantly increased with age. This study used VECTRA H1-270 camera to capture the three-dimensional images, a technology that is very similar to the equipment used for this study. Having obtained non-significant values for inner and outer commissure width for both extraction groups and significant increases in these values for the non-extraction group, it may be possible that orthodontic treatment involving the extraction of premolars could slightly inhibit the natural elongating of the lip width that occurs with age.

6.3 Analysis of Buccal Corridor width and Philtrum Height

It is currently known that buccal corridor width is influenced by multiple variables, including maxillary and mandibular arch form, vertical facial pattern, transverse skeletal width of the maxillary, smile arc and buccolingual inclination of the posterior teeth (Meyers, 2014). The evidence behind whether premolar extractions cause an increase in buccal corridor width and narrow the smile is variable. In 2002, Gianelly measured arch width on plaster models of patients with four first premolar extractions and found no significant results that indicate that orthodontic treatment with extractions result in narrower dental arches when compared to non-extraction treatment. This indicates that extraction treatment with four first premolars does not contribute to the increase in buccal corridor width (Gianelly, 2002). It should be noted, the width of the dental arch in the posterior region is just one of the variables that can affect buccal corridor space. The current study is the only known investigation using three-dimensional images of smiling subjects to determine changes in the buccal corridor width due to extractions. The findings were that the buccal corridor width did increase in all three groups but was only statistically significant in the extraction of upper and lower first premolar group. The extraction of upper and lower first premolar group had the largest difference in average buccal corridor width and the non-extraction group had the smallest difference. Meanwhile, the mean difference for all three groups was less than a 1 mm increase. If arch width was the primary determinant of buccal corridor width, then it would be assumed that extraction of upper first premolars only and extraction of upper and lower first premolars would cause a significantly narrower maxillary arch, resulting in larger buccal corridor width post-treatment. Since the results of this study do not show this, it can be concluded that there are multiple variables that influence buccal corridor width, and that the changes in buccal corridor width that result from extraction treatment is minimal (>1 mm between both sides).

The philtrum height increased minimally in both extraction groups with a greater increase in the four premolar extraction group and a minimal increase in the non-extraction group. However, none of these groups showed a statistically significant change. The expected result for this variable was that extraction treatment would increase philtrum height due to the uprighting of the incisors causing a more obtuse nasolabial angle, inferior displacement of the upper lip, increasing the distance between subspinale (middle of the base of the nose) to the most inferior portion of the upper lip on the vermillion tip. The results of this study showed a very minimal change, indicating that incisor uprighting does not have a significant effect on this measurement.

6.4 Analysis of Incisor Movement

When determining whether the three groups had a statistically significant change between them, the difference in interincisal angle pre-treatment to post-treatment was significant between the non-extraction group to both extraction groups but not between the two extraction groups. U1-NA was significant between the non-extraction group and extraction of upper and lower first premolar group. Changes in U1-NA resulted in a significant change in outer commissure width for the extraction of upper and lower first premolar group. Decrease in the U1-NA angle was 11.7x greater for extraction of upper and lower first premolars compared to the non-extraction group and 7.6x greater when compared to the extraction of upper first premolars only. Similarly, change in interincisal angle for extraction of upper and lower first premolar group was 2.5x greater than the non-extraction group and 1.5x greater for the extraction of upper premolars only group. This indicates that upper and lower incisor retraction due to premolar extractions does influence outer commissure width. However, since only the extraction of upper and lower first premolars group was statistically significant, it is likely that a greater amount of incisor uprighting is achieved when four premolars are extracted compared to only upper first premolars which caused a significant change in outer commissure width. It is important to note that neither of the incisor angulation measurements had a significant effect on buccal corridor width, indicating that a posterior movement of the lips due to incisor uprighting does not cause a significant change in buccal corridor width.

6.5 Analysis of Qualitative results

It was hypothesized that the subjects who experienced an increased inner and outer commissure width due to orthodontic treatment would show a posterior change (green) in the color histogram and that subjects with a minimal difference of these measurements would show no change (blue) in the color histogram. The results of the qualitative analysis were variable although there were some distinct trends, particularly in the extraction of upper and lower first premolar group. That treatment group showed the highest percentage of subjects with anterior movement in the inner and outer commissure width and philtrum. It was expected that a greater change in incisor inclination would cause more of a posterior change in the commissure and philtrum area. Since the extraction of upper and lower first premolar group had the greatest change in incisor inclination, we expected to see a higher percentage of posterior movement (green) on the histograms, but more anterior movement (red) was observed unexpectedly. The non-extraction group had the highest percentage of subjects who experienced little to no change for the outer commissures and about half of the subjects experienced no change in the philtrum. These results were consistent with our prediction that the non-extraction group would have the least amount of change in all the variables. The extraction of upper first premolars only group displayed the most variable results, with almost an equal number of subjects experiencing posterior, anterior and no change for all variables. This is most likely due to the decreased number of subjects included in this treatment group. The variability in the qualitative analysis may be due discrepancies in the superimposition of the pre- and post-treatment images as well as the challenge of patients being able to reproduce the same exact smile and head position for the post-treatment image as was captured in the pre-treatment image. These differences would be reflected in the histogram. In order to increase the accuracy of the superimpositions, there must be standardization of the image acquisition process. By standardizing the process of positioning each patient in natural head position, ensuring that teeth are in occlusion while smiling, and removing all jewelry and hair covering the ears, image quality and the ability to superimpose the images more accurately would be greatly increased.

6.6 Limitations of the Study

The limitations of all stereophotogrammetry systems, including 3dMD Face System, are the possibility of distortion due to movement of the subject and the difficulties of superimposition due to inability of the subject to replicate the same facial expression repeatedly. Small distortions in the images due to movement or inability replicate the same smile in the pre- and post-treatment images could result in small discrepancies of the inner and outer commissure width measurements. In standard photography, in order to capture an image without any distortion due to movement, the image must be captured in least in 1/500th of a second and 3dMD Face imaging system shooting duration has been stated as 1/650th of a second, which should significantly reduce distortion (Akan, 2021).

Currently, the 3dMD Face software is the gold standard for three-dimensional imaging but the evolution of this technology is constantly evolving. The price of this technology, as well as the space requirement for multiple cameras and extensive equipment has clinicians looking for simpler and cheaper solutions. More recently, some smartphone apps are being used in clinical practice. Using a smart phone with a mobile true depth camera, the clinician can capture the face in three dimensions and then use an image processing software program for superimpositions and volumetric measurements. This technique can reduce the cost of three-dimensional facial scanning and is much more mobile than traditional stereophotogrammetry systems (Akan, 2021). The differences between smartphone data capture and traditional stereophotogrammetry is that the smartphone data capture requires more time and more technique-sensitive steps to processes and produce the virtual 3D model, while 3dMD can produce an 3D image file in a single static pass without additional processing steps. The data on the accuracy of these smartphone programs is limited and more studies are needed to determine the overall value compared to systems like 3dMD.

6.7 Clinical Applications

The aims of this study were to determine whether orthodontic treatment with extractions and incisor inclination change has an effect on the commissures, buccal corridor width and philtrum height. The results of this study indicate that extraction of upper and lower first premolars and extraction of upper first premolars only have very small effects on these variables. Clinically, this is important to know when treatment planning for patients with large pre-treatment buccal corridor width, large outer and inner commissure widths and increased philtrum height. Extraction treatment does not seem to have a significant effect on these structures, except for buccal corridor width which exhibits less than a 1 mm change on average.

6.8 Confounding Variables and Future Directions

This study was able to find significant results related to changes in commissures due to orthodontic treatment. The number of confounding variables, however, cannot be ignored. The differences in lip thickness among ethnicities and gender as well as the growth potential of the subjects used in this study may have a confounding effect on the results. Future studies using a more homogenous and non-growing population would be beneficial to eliminate some of these confounding factors. The technology of three-dimensional imaging is only growing in the field of orthodontics and can be a valuable tool not only for analyzing differences due to orthodontic treatment, but also for diagnosing facial asymmetries and craniofacial anomalies more accurately, orthognathic surgery planning, and much more. The accuracy and precision that 3dMD provides only increases its potential for diagnosing, treatment planning, analyzing treatment outcomes and providing patients with the best overall quality of care in the field of orthodontics.

CHAPTER 7

CONCLUSIONS

1. Extraction of either all four premolars or upper premolars only does not appear to be associated with a significant change in inner or outer commissure width.
2. Average buccal corridor space increased minimally for all three groups but was only statistically significant for extraction of upper and lower first premolar group. The average change for all three groups was <1 mm. Extraction of upper and lower first premolars was a significant positive predictor for increased buccal corridor space.
3. Changes in philtrum height were minimal in all three groups accounting for age, treatment time, gender indicating that this is a relatively stable structure during growth and orthodontic treatment.
4. Incisor inclination was strongly associated with four first premolar extractions and resulted in a significant change in outer commissure width.
5. Soft tissue changes with orthodontic treatment have been well studied using two-dimensional images but additional studies using three-dimensional images are needed.

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APPENDIX A: IRB APPROVAL

Temple University
Office of the Vice President for Research

Research Integrity & Compliance
Student Faculty Center
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Institutional Review Board
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Approval for a Project Involving Human Subjects Research that Does Not Require Continuing Review

Date: 01-Dec-2020

Protocol Number:	27447
PI:	TUNCAY, ORHAN
Review Type:	EXEMPT
Approved On:	01-Dec-2020
Committee:	A1
School/College:	DENTAL SCHOOL (0700)
Department:	DENTAL (07000)
Sponsor:	NO EXTERNAL SPONSOR
Project Title:	"Effects of Orthodontic Treatment on Commissures in Adult Patients"

The IRB approved the protocol 27447.

The study was approved under Exempt or Expedited review. The IRB determined that the research **does not require a continuing review**, consequently there is not an IRB approval period.

APPENDIX B: PRE- AND POST-TREATMENT MEASUREMENT DIFFERENCES FOR ALL SUBJECTS

Patient Identifier	**Group**	**ICW 0**	**ICW 1**	**OCW 0**	**OCW 1**	**BC0R**	**BC0L**	**BCAvg 0**	**BC1R**	**BC1L**	**BCAvg 1**	**PH 0**	**PH 1**	**IA 0**	**IA 1**	**U1-NA 0**	**U1-NA 1**
1	1	56.84	54.48	63.62	65.59	4.51	5.71	5.11	7	5.88	6.44	12.71	14.79	118.9	115.7	23.2	20.4
2	1	49.59	55.86	71.46	73.55	12.04	12.09	12.065	10.5	10.87	10.685	10.32	9.39	120.5	117	19.3	18.6
3	1	46.47	47.07	56.8	59.12	5.59	5.09	5.34	6.72	6.76	6.74	10.9	13.23	137.2	118.1	21	27.9
4	1	54.13	51.03	65.68	61.53	4.94	6.88	5.91	6.15	4.86	5.505	12.95	11.92	122	129.7	18.1	12.9
5	1	44.98	56.17	59.51	69.07	7.13	8.46	7.795	5.52	7.86	6.69	10.98	9.19	115.4	117	32.5	27.4
6	1	52.09	52.62	61.37	61.35	5.31	5.67	5.49	4.87	4.08	4.475	13.3	11.53	132.7	122.3	26.1	22.3
7	1	55.82	57.36	66.16	67.21	4.57	7.26	5.915	5.9	6.37	6.135	12.77	10.31	137.2	116.9	13.1	26.2
8	1	47.54	44.17	58.7	56.23	5.84	9.13	7.485	6.64	6.42	6.53	9.33	10.37	125.7	116	25.4	20.9
9	1	52.69	56.63	65.77	70.57	7.02	6.38	6.7	7.33	7.33	7.33	13.68	12.82	121.5	120.3	31.1	30.1
10	1	47.38	47.75	54.49	55.12	3.35	4.48	3.915	3.99	4.46	4.225	14.87	14.69	123.6	128.3	25.7	24.3
11	1	51.89	53.7	59.7	62.26	3.47	4.72	4.095	4.48	4.5	4.49	8.21	5.28	107.8	120	30.9	29.2
12	1	50.94	53.94	61.9	64.21	6.85	4.33	5.59	6.37	4.3	5.335	10.75	12.6	141.1	112.8	9.8	23.9

13	1	44.06	41.31	53.97	53.16	5.87	6.57	6.22	6.72	6.74	6.73	12.56	13.64	126.1	125.1	33.6	32.1
14	1	50.47	52.69	59.59	64.63	3.96	6.15	5.055	6.9	5.58	6.24	11.35	12.78	150.2	133.7	1.8	13.3
15	1	53.15	57.53	60.82	65.91	4.89	4.43	4.66	6.02	4.43	5.225	12.86	11.77	128.4	129.3	14.6	16.3
16	1	49.16	54.45	63.58	66.13	8.13	7.42	7.775	7.27	6.42	6.845	11.44	11.95	137.4	132.7	10.6	16.8
17	1	48.81	40.82	58.01	52.15	4.74	5.61	5.175	6.98	5.84	6.41	13.64	13.83	106.4	122.4	40.8	26.3
18	1	53.96	56.91	63.01	65.79	6.75	4.28	5.515	5.95	3.92	4.935	13.53	12.21	120.1	104.5	25.6	33.8
19	1	51.94	53.65	66.36	64.22	8.09	8.28	8.185	7.59	6.24	6.915	10.61	12.61	121.5	110.2	23	25.6
20	1	46.64	55.11	67.94	75.97	11.91	12.65	12.28	11.61	12.8	12.205	9.51	10.55	122.6	129.8	25.9	15.5
21	1	51.97	56.28	60.8	61.02	4.37	5.78	5.075	2.44	2.89	2.665	12.97	13.83	126.4	113.3	27.7	33.9
22	1	42.97	49.35	54.12	64.93	6.68	4.75	5.715	10.35	6.66	8.505	15.68	12.88	120.5	117	19.6	23.9
23	2	52.38	52.88	65.85	69.85	7.68	5.99	6.835	7.41	10.24	8.825	9.14	13.23	123.5	115.3	20	31.5
24	2	50.54	57.49	65.42	69.99	8.86	9.14	9	8.62	9.96	9.29	12.43	11.81	101.8		24.4	
25	2	50.73	45.13	60.68	60.18	5.88	4.62	5.25	9.74	6.87	8.305	11.46	12.16	107.9	127.5	33.3	14.3

26	2	54.46	42.59	70.15	55.34	8.25	9.08	8.665	6.62	7	6.81	5.42	11.29	82.6	127	67.5	29.2
27	2	50.9	51.37	63.97	59.93	6.49	9.09	7.79	6.58	7.4	6.99	10.62	12.03	99.2	111.1	38.9	28
28	2	53.97	60.01	65.04	69.48	6.87	6.47	6.67	5.23	6.17	5.7	13.84	14.41	108.6	129.3	35.9	12.9
29	2	55.53	53.03	67.17	68.72	6	8.02	7.01	7.8	8.81	8.305	9.76	11.31	105.5	118.4	38.2	14.3
30	2	56.56	57.21	72.37	76.91	10	9.36	9.68	11.8	10.23	11.015	6.52	7.43	127.3	122.4	21.9	22.3
31	2	55.92	60.24	68.5	74.71	7.25	6.25	6.75	9.38	11.22	10.3	15.02	15.15	109.6	125.3	30.4	7.3
32	2	51.58	50.22	65.64	65.43	6.14	8.25	7.195	8.52	7.7	8.11	8.56	15.15	115.8	123.2	35	25.9
33	2	56.04	58.58	72.04	78.12	7.99	8.94	8.465	10.87	10.18	10.525	12.08	11.86	98.2	112.5	39.1	37.8
34	2	54.65	52.81	72.44	71.28	9.43	9.9	9.665	10.24	11.38	10.81	11.45	12.04	103.1	117.9	27	21.5
35	2	44.66	51.93	59.66	66.24	8.11	10.4	9.255	8.6	7.37	7.985	15.98	11.84	124.4	127	15.3	9.7
36	2	52.51	48.86	62.82	62.69	5.5	5.53	5.515	8.27	8.32	8.295	10.31	12.01	118.7	123.8	12.5	9.9
37	2	52.39	56.3	64.04	71.74	6.1	6.4	6.25	9	7.96	8.48	14.77	15.08	127.1	137.3	18	12.6
38	2	55.19	53.99	64.69	63.87	4.77	6.33	5.55	4.98	5.82	5.4	11.75	11.92	106.2	136.4	22.8	3.4
39	2	57.93	56.96	67	67.87	5.85	5.69	5.77	9.13	4.95	7.04	16.04	16.51	110.2	112.2	34.7	21.6

40	3	48.23	59.18	62.44	72.11	7.62	8.05	7.835	8.59	10.07	9.33	13.27	14.34	112.2	123.2	32.4	17.7
41	3	52.52	59.35	64.98	70.1	6.28	7.35	6.815	4.38	7.04	5.71	15.49	15.22	125.9	120.8	16.9	21.7
42	3	52.56	53.72	66.2	70.85	6.6	8.04	7.32	9.76	9.24	9.5	13.74	14.41	113.5	114.3	25.8	14.4
43	3	60.57	59.55	73.55	73.74	8.5	6.91	7.705	7.41	8.93	8.17	15.39	12.23	107.2	125.6	21.8	18.9
44	3	54.85	54.01	69.79	66.79	7.42	9.61	8.515	7.72	6.21	6.965	13.55	14.24	120	142.6	22.8	11
45	3	55.75	52.35	69.76	70.72	8	7.66	7.83	10.45	8.55	9.5	8.22	10.45	122.3	129.3	29.6	15.2
46	3	44.96	50.59	58.08	59.71	7.82	6.42	7.12	6.23	5.98	6.105	7.93	10.29	116.7	116.1	25.2	25.5
47	3	50.99	61.7	59.2	72.64	4.42	4.42	4.42	6.13	5.82	5.975	13.05	12.93	109.7	124.3	39.7	28.6

APPENDIX C: SOFT TISSUE COLOR CHANGES FOR EACH SUBJECT

Subject	Treatment Group	Right inner commissure	Left Inner commissure	Right Outer commissure	Left Outer commissure	Philtrum
1	1	0	-	0	0	0
2	1	0	0	0	0	0
3	1	0	--	0	--	0
4	1	--	+	--	0	-
5	1	-	-	--	--	-
6	1	0	+	0	0	+
7	1	+	+	0	0	-
8	1	0	++	0	+	0
9	1	+	--	0	0	0
10	1	++	0	++	0	0
11	1	++	0	0	0	+
12	1	0	0	--	0	0
13	1	+	+	+	+	0
14	1	+	++	--	0	0
15	1	--	--	--	--	0
16	1	-	-	-	--	-
17	1	+	+	++	+	+
18	1	0	0	0	--	--
19	1	+	+	+	+	+
20	1	0	-	--	0	+

21	**1**	+	+	**0**	**0**	+
22	**1**	+	**-**	**0**	**0**	**-**
23	**2**	**0**	**-**	**0**	**0**	**0**
24	**2**	+	+	**0**	**0**	**0**
25	**2**	**0**	+	**0**	+	**--**
26	**2**	++	++	++	++	**-**
27	**2**	**0**	+	**0**	**0**	+
28	**2**	**0**	+	**0**	+	+
29	**2**	++	++	+	+	+
30	**2**	**--**	**--**	**0**	**--**	**0**
31	**2**	**--**	**--**	**--**	**--**	**-**
32	**2**	**0**	**0**	++	++	+
33	**2**	+	**0**	+	**0**	+
34	**2**	+	+	**0**	**0**	+
35	**2**	**--**	**--**	**0**	**0**	+
36	**2**	**0**	+	**0**	**0**	**-**
37	**2**	**0**	**0**	**--**	**--**	**0**
38	**2**	+	+	++	++	**0**
39	**2**	**0**	+	**0**	**0**	**-**
40	**3**	**0**	**0**	**0**	**0**	**-**
41	**3**	**-**	**-**	**--**	**--**	+
42	**3**	+	**0**	+	**0**	**-**
43	**3**	**0**	**0**	**0**	**--**	**0**

44	**3**	+	++	+	**-**	**-**
45	**3**	**0**	++	**0**	+	+
46	**3**	**--**	**--**	**0**	**0**	**0**
47	**3**	**0**	**--**	**--**	**--**	**0**