RETROSPECTIVE THREE-DIMENSIONAL FACIAL SOFT TISSUE ANALYSIS IN SKELETAL CLASS I MALOCCLUSIONS WITH PREMOLAR EXTRACTIONS

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ABSTRACT

Objectives: Decreased volume and atrophy are hallmarks of aging facial soft tissues. In perioral region, a hallmark is deepening of nasolabial folds. It is unknown how extraction orthodontic treatment affects such tissues. This study describes nasolabial fold regional changes in premolar extraction cases.

Methods: Pre- and post-treatment 3dMD images of 14 skeletal Class-I patients with 4 premolar extractions were studied for changes of tissue thickness in the nasolabial fold region. All subjects were treated at Temple University. The sample consisted of 10 females and 4 males aged 12 -26 years old and included three ethnicities: Asian, Hispanic, and African American. With the aid of 3dMD Vultus software, both qualitative and quantitative analyses were collected. Color histograms were created for qualitative analyses, and quantitative volumetric changes in cheek volume were correlated to 2-D cephalometric lip thickness, lip retraction, and incisor retraction. Data were analyzed by Spearman's rho for lip thickness, lip retraction, and incisor retraction. Regression analyses were completed controlling for age, gender, and ethnicity.

Results: In this sample of Class-I malocclusion patients with 4 premolar extraction treatment, quantitative results showed no significant correlations were found between 2-D soft tissue thickness and volumetric changes around the nasolabial fold region. Moreover, none of the other characteristics including, change in the upper lip in 2-D cephalometric measurements, age, and gender were factors that correlated with volumetric changes around the nasolabial fold. The qualitative findings showed changes in lips and commissures did not affect the soft tissues around the nasolabial fold areas.

Overall, there were no significant correlations between the thickness of soft tissue, change in the lips in 2-D, age, ethnicity, and gender in volumetric changes.

Conclusions: Data generated by this investigation did not imply any cause-and-effect relationship between measurements of lip thickness, lip retraction, and incisor retraction to the deepening of the nasolabial fold.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Over the past few centuries, humans have evolved to be more aware of their social acceptance. With the idea proposed by Ackerman that "appearance is often valued more than performance (Ackerman, J., et al., 2012)," the goal of orthodontic treatment has now shifted towards enhancement of normal traits and to increase social acceptance and well-being (O'Doherty, J., 2003). As many patients seek orthodontic treatment with the primary motivation of improving their facial attractiveness, orthodontists today, aim to improve facial appearance and smile of their patients as their primary goal (Burden, D., 1995).

Facial attractiveness is difficult to measure and subjective to the viewer. There is no "ideal" or perfect face, but appearance of youthfulness remains a constant hallmark of esthetics (Han, A., et al., 2014; Ehlinger-Martin, A., et al., 2015). The most significant attributes of a youthful face is the volumetric distribution of the soft tissues. With age, the soft tissue volume changes and reduces due to atrophy and hypertrophy. This ultimately leads to the appearance of lines and increased skin laxity in the soft tissues. In the perioral region, one of the hallmarks of aging is the prominence of the nasolabial folds as the cheek tissues gradually descend with the pull of gravity (Guyuron, B., et al., 2004; Pessa, J., et al., 1998). However, the effects of this change have yet to be explored with orthodontic treatment.

Orthodontic treatment exhibits most changes in the perioral region. In order to provide the greatest benefit of orthodontic treatment, the patient's perspective of their change of appearance is heavily weighed. The significance of change in the nasolabial fold with orthodontic treatment with extractions may be questioned. It is known that soft tissue measurement is not always in proportion to the hard tissue measurements (Hershey, H., 1972; Garner, L., 1974; Wisth, P., 1974; Rains, M., et al., 1982; Talass, F., et al., 1987; Yogosawa, F., 1990; Diels, R., et al., 1995; Kasai, K., 1998; Caplan, M., et al., 1997; Xu, Y., et al., 2017). One of the reasons for this variability is due to the differences in the thickness of the soft tissues, which also determine the final facial profile (Burstone, C., 1967; Subtelney, D., 1961; Merrifield, L., 1966; Ricketts, R., 1968; Holadaway, R., 1983; De Smit, A., et al., 1984). In order to satisfy the goals of the patients, changes that can occur with orthodontic treatment must be fully understood.

Temple University Kornberg School of Dentistry, Podray clinic has been a pioneer of 3-dimensional imaging. 3dMD face system (Atlanta, GA) is a reproducible and reliable system that produces 3-dimensioan images using stereophotogrammetry and structured light technique that allows examination of the soft tissues (Aldridge, K., et al., 2005; Dindaroğlu, F., et al., 2016; Kau, C., 2007; van der Meer, WJ., et al., 2014). Previous studies evaluated changes in perioral structures including the commissures, nasolabial angle, and mentolabial fold with orthodontic treatment (Croft, D., 2009; Franklin, B., 2009; Papasikos, J., 2013; Uffner, N., 2013). In continuation, the changes of nasolabial fold will be examined to understand the changes in the 3-dimensional view.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Effect of Nasolabial fold and Facial attractiveness

2.1.1 Facial Attractiveness

Facial attractiveness is a prized entity in every person's daily life. From the moment humans are born, infants and newborns prefer to look at attractive faces regardless of the gender, race, or age. Attractive babies also tend to receive more attention naturally and attractive children are punished less severely by adults (Langlois, J., et al., 1987; Slater, A., et al., 1998). As adults, attractive people are perceived to be more qualified and generally have more self-esteem; self-confidence in their personal life (Bashour, M., 2006; Dion, K., 1972; Byrne, D., 1968; Kleck, R., 1975; Perrin, F., 1921). A person's facial attractiveness is an important asset from the moment of birth. However, facial attractiveness is difficult to measure and thus is subjective to the viewer. Kingsley has described attractiveness to be the harmonious relationship between the dentition and the facial configuration despite the infinite diversity forms of jaws (Kingsley, N., 1880). Although there is no "ideal" or perfect face, there are some predominant psychological factors that influence facial attractiveness. These factors include spatial configuration which includes averageness, symmetry, and youthfulness (Chen, A., et al., 1997; Sarwer, D., et al., 2003). Whereas the ideal beauty may vary, the appearance of youthfulness remains a constant benchmark for esthetics (Han, A., et al., 2014; Ehlinger-Martin, A., et al., 2015). A closer examination of the components of the appearance of youthfulness should be further investigated.

2.1.2 Youth and attractiveness

Youth in facial attractiveness is evident through the trends seen in fashion magazines. Observation of facial profiles in fashion magazines over time depicts the changes in perception of facial profile attractiveness. The facial profiles observed depicted a significant increase in the protrusion of lips, increased lip curl, and increased vermillion display, all indicating a preference towards a more anteriorly positioned lips. Some suggest the more anteriorly positioned lips portray a more youthful and desirable look from an aesthetic viewpoint (Nguyen, D., et al., 1998; Auger, TA., 1999). This theory can be scientifically supported on the growth of lips which reach their greatest growth between the ages of 12-14 (Mamadras, A., 1984). Consequently, as lips age, a natural flattening in overall profile including the protrusive lips can be seen being perceived as less youthful and thus less attractive (Mamandras, A., 1984; 1988). The lips have shown a significant prominence changing the trend of attractiveness. However, the surrounding parameters need to be in relative balance as it will influence the perceptions of attractiveness greatly (Denize, E., 2014), including the nasolabial fold.

2.1.3 Nasolabial fold effects in facial esthetics

The most significant attributes of a youthful human face is the volumetric distribution of its soft tissues. In a youthful face, the soft tissue structures frame expressive features of the eyes and mouth and remain full and well positioned (Little, J., 2000). Chronological aging can change the smile and smile lines gradually throughout an individual's life time (Miller, C., 1989). As the soft tissue volume change with aging, reduced volume due to atrophy and hypertrophy causes a disruption in the smooth arcs that are normally portrayed in a youthful face (Donofrio, LM., 2000). As soft tissue undergoes atrophy and hypertrophy with time, the appearance of fine lines and increased skin laxity in the soft tissues. Fat atrophy, gravity-induced soft tissue redistribution, and reduction of facial skeletal support related to bone resorption all are changes that occur in the face over time (Han, A., et al., 2014). One of the hallmarks of aging in the peri-oral region is the nasolabial folds. These 'fold muscle' bundles arise from development of superficial fascia underneath the dermis. The septum between nasolabial fat and medial cheek fat compartmentalizes fat to create this anatomical structure (Tsia, F., et al., 2010). Through aging, and with the pull of gravity, the cheek tissues gradually descend which create a more prominent nasolabial fold (Guyuron, B., et al., 2004, Pessa, J., et al., 1998). With the turn of the century, fine lines, wrinkles, and loss of tonicity become an increasing area of concern and awareness that play a role in facial aging (Ehlinger-Martin, A., et al., 2015). It has been postulated that a selective reduction in the fat tissues of the hypertrophic cheek can better simulate the smooth arcs portrayed in a youthful face (Gosain, A., 2005). How will orthodontic treatment affect this change?

2.2 Purpose of Orthodontic treatment

2.2.1 Goals of Orthodontic treatment

Many patients seek orthodontic treatment with the primary motivation of improving their dental and facial appearance to improve their facial attractiveness (Burden, D., 1995). Orthodontists today, aim to improve facial appearance and smile of their patients as the primary goal. Also they strive to establish a harmonious occlusion of the dentition by placing them in a functional and stable position within the alveolar bone. However, this was not the case 40 years ago. Edward Angle, who pioneered orthodontic specialty, believed that malocclusions were a threat to oral health as they caused imbalance in occlusal loading and interfered with oral hygiene (Ackerman, J., et al. 2012). This was Angle's clinical judgment and not supported by scientific studies (Burden, D., 1995; Mohlin, B., 2003). It might be asked why do patients still seek orthodontic treatment? According to Ackerman, "the idea that appearance is often valued more than performance is simply a fact of life (Ackerman, J., et al., 2012)." Over the century, humans have evolved to become more aware of their social acceptance. With the increased societal values and pressures, patient's need for orthodontic treatment has shifted towards enhancement of normal traits to increase social acceptance and well-being (O'Doherty, J., 2003).

The benefit of orthodontic treatment now heavily weighs on the patient's perspective of their change of appearance and their psychosocial benefits rather than the correction of their malocclusion. The orthodontists must then rely on the qualitative societal and cultural standards as their treatment goals, and be able to adapt to the changes over time (Ackerman, J., et al., 2012). Despite the improved perception of social well-being and quality of life in orthodontic patients, numerous findings indicate that there are no significant or measureable differences in the patients' self-image or self-esteem (Cunningham, C., 2007; Liu, Z., et al., 2009; Marshamn, Z., 2007; O'Brien, C., et al., 2007). Therefore, the primary goal of orthodontic treatment now must focus on enhancement of dentofacial appearance to improve the patients' social well-being and quality of life.

2.2.2 Different perception of profiles

In order to provide an improved perception, the patient's desire and awareness must also be analyzed. Do orthodontists and patients have similar goals in their treatment outcome appearance? Studies do answer this question have been published to determine the perception tolerability between orthodontists and patients. In a study which used computer morphing program to animate profiles, they found that while orthodontic patients are the least tolerant of the variations in their profiles compared to non-orthodontic patients, orthodontists were most tolerable of variations to different profiles (Kitay, D., et al., 1999). There is a dispute in regards to the unexpected misrepresentations of the use of computer morphing program to animate profiles. However, the realistic representations with photoediting in morphed images are difficult to determine.

Tolerability or the zone of acceptability (ZA) was also compared in patients' profiles who were receiving orthognathic surgery. In this study, the perceptions of the patient, their "significant others", orthodontists, and oral surgeons were measured.

Again, this study was in agreement that the patients themselves had the smallest zone of acceptability, followed by the surgeons, then by their significant other, and lastly the orthodontists with the largest zone of acceptability (Arpino, V., et al., 1998).

Despite the patient's smallest tolerance to variability in profiles of others however, patients' perception of oneself can be far from accurate. Especially in the profile view, patient's perception of themselves can be affected by other factors. One large contributing factor is their psychological self-satisfaction. Patients who exhibit high self-esteem are more likely to judge their profiles to be significantly more ideal than their objective appearance, and conversely, patients with low self-esteem are more likely to judge their profiles to be significantly less ideal than their objective appearance (Pitt, E., et al., 1995). Orthodontists must correctly diagnose and understand the patients' motive for orthodontic treatment need to be able to positively impact the patient's quality of life with orthodontic treatment.

2.2.3 Cultural aesthetic preferences

Preferences in facial appearance can also vary between different ethnic groups. Many of the norms created for cephalometric measurements have been completed via measuring Caucasian adult females, and should be used in caution to evaluate non-Caucasian patients. When preferences were studied between different ethnic groups, white orthodontists generally preferred flatter profiles in comparison to black orthodontists, and black women preferred even fuller profiles than the black orthodontists (McKoy-White, J., et al., 2006). When parents evaluated their preference on their children, Caucasian parents preferred less protrusive upper lip but increased lower lip prominence while African American parents preferred less protrusiveness of both upper and lower lips, especially on their sons. It was found that both ethnic group parents related fuller lips and Class II tendency to be a feminine feature and preferred a stronger chin for their sons (Smedley, C., 2003).

In Puerto Rican Hispanics, “good looking” faces were evaluated by Puerto Rican panel of judges including orthodontists, parents, and peers. The three groups of panels conclusively had similar preferences with a slight Class II posterior divergent convex profile, slight mandibular retrusion, and upright upper and lower incisors. They also preferred longer face in males and shorter face in females (Hernandez-Loring, J., 1997). This was also similar to Mexican-Americans who preferred less protrusive lips when compared to the preferences of whites (Mejia-Madil, M., et al., 2005). However, when a group of Hispanic Americans were divided into two groups of influence (lesser western-adapted and higher western-adapted) and their preferences for lip position was compared. The higher western-adapted Hispanic group preferred similar lip position as the Caucasians, whereas to the lesser western-adapted Hispanics preferred a more retruded lip position (Toureno, L., et al., 2014). The Hispanic-American group showed adaptation in their preference to their surrounding population.

Interestingly, this does not follow the same pattern for Korean-Americans. When the preference for acceptable position and most pleasing profile of the female nose and male chin were compared, there was a significant difference between Caucasian orthodontists and Korean-American patients. Korean Americans preferred a more protrusive nose for females and a more retrusive chin for males (Park, Y., et al., 2006).

The variations between ethnic groups make the task of an orthodontist even more difficult as esthetic trends change and differ amongst groups.

2.3 Soft tissue imaging

2.3.1 Orthodontics and soft tissue changes

The founding father of modern American orthodontics, Edward H. Angle suggested that the optimal placement of teeth will result in good facial harmony (Angle, E., 1907). This is invariably un-true and facial harmony is one of the important goals along with occlusal excellence for orthodontists today. Normally, treatment plans for patients are created referencing to the dentoskeletal standards to determine the position of the hard tissue elements; often ignoring the soft tissue thickness factors (Steiner, C., 1953; Tweed, C., 1954; Downs, W., 1956). It was once assumed that the soft tissue naturally will follow the hard tissue, but with increased scientific studies, it is known that soft tissue measurements are not always in proportion to the hard tissue measurements (Hershey, H., 1972; Garner, L., 1974; Wisth, P., 1974; Rains, M., et al., 1982; Talass, F., et al., 1987; Yogosawa, F., 1990; Diels, R., et al., 1995; Kasai, K., 1998; Caplan, M., et al., 1997; Xu, Y., et al., 2017). In extension to the variability, the soft and hard tissue measurements do not always give the same information for a given patient (Park, Y., et al., 1986). One of the reasons for this variability is due to the differences in the thickness of the soft tissues, which determine the final facial profile (Burstone, C., 1967; Subtelny, D., 1961; Merrifield, L., 1966; Ricketts, R., 1968; Holdaway, R., 1983; De Smit, A., et al., 1984). Thus, soft tissues need to be evaluated separately from the hard tissues.

Another ambiguity is the method used today to evaluate soft tissues is that they are limited to 2-dimensional images including, photography and radiographs. Whereas patients assess their appearance from their frontal or their three-quarter profile view, the images that orthodontists use to measure and evaluate the face from is the sagittal view (Sarver, D., 2001). Interestingly, when the accuracy of self-image was measured, frontal 2-dimensional was the most accurate and decreased significantly in 3-dimensions (Becker, R., 2011). Specifically, the 2-dimensional lateral cephalogram and a three-quarter profile photographic view lack depth (Ismail, S., 2002). To provide the best facial appearance in the patient's preferences and views, the orthodontic analysis must complement the way patients assess their appearance.

2.3.2 Evaluation of soft tissue profiles in 2-dimension

Extra-oral photographs in the practice of orthodontics are routinely taken to evaluate the face. A series of standardized photographs are taken to imitate the 3-dimensions of the face including a profile view and ¾ view. Despite the ease of use, these photographs contain significant error from positional orientation of the patient. Consequently, landmarks are poorly reproduced (Tanner, et al., 1949).

In addition to photographs, lateral cephalometric radiographs are also used to evaluate the soft tissues in the profile view. However, similarly to photogrammetry, there are problems with using 2-dimensional image to evaluate a 3-dimensional face. Some of the inaccuracies that arise from 3-dimensional image contained into a 2-dimensional image include: errors of projection, errors in landmark identification, and the reliability of head film measurements (Baumrind, S., 1971).

The first error is the "error of projection" plainly due to the fact that the head film is a 2-dimensional shadow of a 3-dimensional object. During acquisition of cephalogram, the rays are projected from a very small source onto the 3-dimensional object to create a 2-dimensional shadow. This error causes enlargement and foreshortening due to the different distances of the structures projected onto the headfilm. Thus, the resultant image is distorted. This error has also been noted by others including Bjork, Hixon, Brodie and Salzmann (Baumrind, S., 1971).

The second type of error is the "error of identification" which is primarily due to the variability in identifying a 3-dimensional landmark in a 2-dimensional image. Specific landmarks have increased error than others. In areas where the edge folds sharply, such as at the upper incisal edge, it is easier to estimate the landmark. However, for areas where the edge folds in more gradually, such as point A or point B, it becomes more challenging to be able to identify this landmark. Interestingly, the distributions of these errors are systematic for each landmark and usually noncircular in their envelope of error. Another problem is the definition for the landmarks themselves. For example, a landmark that is described as the "more prominent" point can be ambiguous than if it was defined as the most anterior. Weak definitions to describe certain points such as gonion, can lead to errors of identification (Baumrind, S., 1971).

The last error of cephalogram is the error in the reliability of the measurements. The before mentioned error of projection and error of identification all contribute to the last error, the error in reliability of the measurements. When the reliability of measurement was tested however, the absolute values of errors and variability among the replicated measures were greater for the angular measurements compared to the linear measurements. Another important problem to consider is the problem of independence in these estimates. One landmark drawn on a headfilm is used multiple times to find measurements. This inherent error in the inability to produce measurements independently can also influence the reproducibility. It is critical for clinicians to be aware of the problem of independence and the consequences of these errors in a group of measurements from a single tracing (Baumrind, S., 1971). It is proven with scientific evidence that the assessment of a 3-dimensional image on a 2-dimension will inevitably lead to an error (Bjork, A., 1963; Bjork, A., 1969) and that the films must be interpreted carefully in order to obtain reliable information.

2.3.3 Stereophotogrammetry

Stereophotogrammetry is one of the scanning techniques used to capture 3-dimensional images. Stereophotogrammetry uses two cameras to compose stereopair images of the object. Then by means of triangulations, the 3-dimensional features of the face are recovered (Hajeer, M., et al., 2004). By linking this image capture to a simple plotting instrument, stereophotogrammetry has the ability to process complex algorithms to produce a 3-dimensional image from a series of simple photographs (Burke, P., et al., 1967).

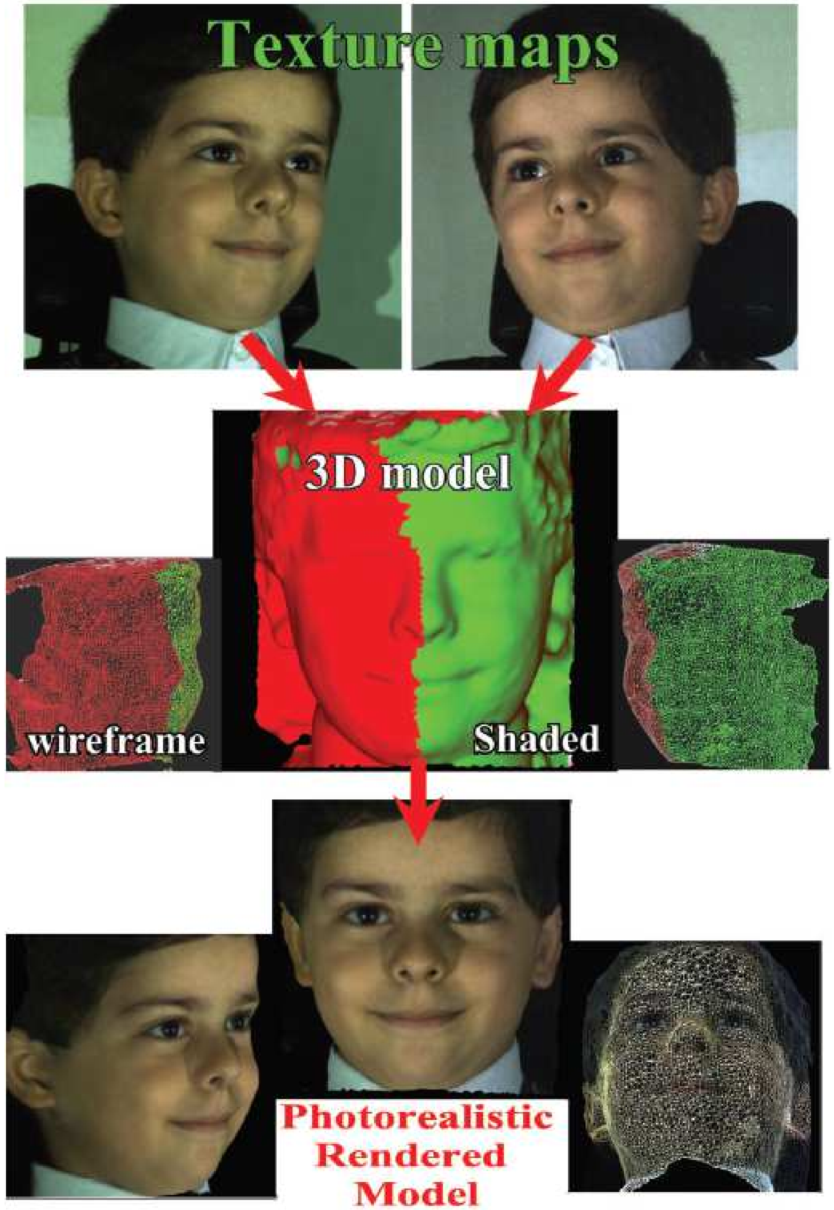


Fig 1. Conversion of stereopair images into real-life 3-dimensional model (Hajeer, M. 2004)

The first step in generating a 3-dimensional model is 'modeling' which is to define the physical properties. The object is depicted first as a 'wireframe' to which surfaces are added by placing pixels into the mesh. Then shading and lighting are added which produces the depths and contours of the object, and lastly, the images are then ‘rendered’ by the computer to convert the data into a 3-dimensional object (Figure 1) (Hajeer, MY., 2004).

2.3.4 3dMDface system

3dMDface system (Atlanta, GA) is a reproducible and reliable system that produces 3-dimensional images using stereophotogrammetry and structured light technique (Aldridge, K., et al., 2005; Dindaroğlu, F., et al., 2016; Kau, C., 2007; van der Meer, WJ., et al., 2014). Eight digital cameras are located both right and left sides of the patient and act as stereopairs to take an image of the patient’s face in matter of seconds. The 3dMD system has a predetermined stereo triangulation algorithm, which then matches the external features to produce a 3-dimensional composite model (Kau, C., 2007). In addition, the 3dMD can produce realistic skin tones of the patient which is layered over the features, producing a 3-dimensional image (Kau, C., 2007). The major advantages of 3-dimensional image are the measurements in three different axes, the Cartesian coordinate system; the x-axis (or the transverse), y-axis (or the vertical) and the z-axis (the anteroposterior or ‘depth’) (Hajeer, M., et al., 2004). With the ability to measure differences in all 3-dimensions, volume changes can also be evaluated.

2.3.5 3-Dimensional images in orthodontics

Orthodontists have a critical role in improving facial appearance. Hence, morphologic changes with orthodontic treatment have always been a curiosity to orthodontists. Traditionally, changes were studied in the 2-dimensional lateral cephalogram. Now, with 3-dimensional imaging, it is possible to study growth in 3-

dimensional view that would provide a more thorough understanding of the soft tissue effects of orthodontic treatment. With the paradigm shift of working ‘inwards’ from the external soft tissues, as these are what people determine facial appearance with, the use of 3-dimensional imaging is becoming increasingly clinically significant (Holdaway, R., 1983; Arnett, G., 1993). The use of 3-dimensional imaging is efficient with its short duration of time needed to capture the image, and the ability to produce morphologic soft tissues efficiently without use of radiation to the patient is a big advantage (Moss, JP., 1991; Ayoub, AF., 1996; Ferrario, VF., 1993; Nyugen, C., 1999). The 3-dimensional images are diagnostic information that can be used in clinical orthodontics.

Three-dimensional images can be used to create templates to compare diagnoses and analyze treatment outcomes. Particularly in patients who present with facial disproportions, descriptive analyses could be provided to assist in diagnosis (Kau, C., 2006). These methods will help orthodontists improve their analytical ability, as well as, to further execute their treatment modalities. In addition, the 3-dimensional images have great impact on orthognathic surgery with increasing number of patients undergoing surgery to correct their underlying skeletal discrepancy (McCane, A., 1992). With orthognathic surgery, there is an increased change on the face appearance and is thus a necessity to analyze these patients face 3-dimensionally (Tuncay, OH., 2001).

2.3.6 Reliability of 3-dimensional measurements

In order to justify the use of 3-dimensional images, measurements must be reliable; especially, because the soft tissues are difficult to accurately assess (Mah, J., 2003). The soft tissues are difficult due to the affect from muscle tone, posture, BMI, or even sodium intake. Studies have focused on the reliability of the measurements obtained from 3-dimensionally generated images. Some studied the measurements based upon certain point landmarks on live subjects (Ayoub, A., 1998; Aung, S., et al., 1995; Coward, T., et al., 1997; Nyguen, C., et al., 2003) and some studies formulated a complex mathematics to analyze the shapes of the faces (Hennessy, R., et al., 2001; Coombes, A., et al., 1991). Another study evaluated the reproducibility by measuring on certain point landmarks, outer and inner canthus of the eyes, and nasal tip then fine registered for best fit. Generally, the analysis showed that reproducibility could be achieved, with the greatest errors being in the lower jaw area due to the freely moving mandible (Kau, C., 2008).

The most reliable method for measuring 3- dimensional images has been to use the surface-based alignment algorithm (Iterative Closest Point Algorithm) of the best-fit alignment. This alignment is reported to have a minimum error value ranging from 0.39 to 0.52mm (Maal, T., et al., 2010). The most commonly preferred region that is used to superimpose on facial 3-dimensional images is the forehead, which is not expected to change (Maal, T., et al., 2011; Hajeer, M., et al., 2002). These 3- dimensional imaging studies support reliability, reproducibility, and its potential for use to assess the changes in facial changes with growth, orthodontic treatment, and orthognathic surgery.

2.4 Clinical use of 3-dimensional imaging

2.4.1 Growth changes in soft tissues in 3-dimension

Currently, with a greater emphasis placed on the soft tissues, further understanding of change in soft tissues with growth is warranted. Yet, most of the growth studies are based on the changes in hard tissues from the lateral cephalograms. There are only limited studies that analyze the soft tissue changes with growth in a 3-dimensional view (Riolo, M., 1987). There is lack of longitudinal studies of the soft tissues in the 3-dimension, and further studies are necessary (Kau, C., 2008).

One study attempted to study the growth changes in soft tissue 3-dimensionally. Fifty-nine children aged 12 to 14 years of age without orthodontics with a normal body mass index were evaluated over 2 year period. The growth changes noted were greater average facial growth with boys compared with girls. This has also been shown in previous studies (Vig, KW., 2000; Bishara, SE., 2000). There was a general trend of downward and forward growth of the nose area in relation to the soft tissue nasion. A general increase in the vertical dimension was noted and as the nose grew, the lips were translated in a downward direction. In depth, the eyes deepened as the brows became more prominent, and the cheeks on both sides tended to flatten with age (Kau, C., 2008).

In another study, cross-sectional data were used to observe growth changes in the ages 5 to 10 years old (Nute, S., 2000). In this study, they observed a growth pattern in these subjects. There was a smaller increase in the mid-face region compared to a greater increase in the lower face. This result also agrees with other studies (Canon, J., 1970; Nanda, S., 1992). The mid facial prominence did not change greatly, while there was notable increase in the mandibular width with growth with the greatest increase at the inferior part of the mandibular region. The nose increased in height and prominence with increased width of the alar base with increasing age. There were no sex differences noted. All of the dimensional changes were greater than the cephalometric hard tissue measurements. This variability was attributed to the inclusion of soft tissues in this study which does not strictly correlate to the hard tissues, as previously mentioned. In addition, some of the depth changes with growth were deepening of the eyes and flattening of the cheeks (Kau, C., 2008). With the use of 3-dimensional images, the changes in the facial width and prominence were able to be evaluated which otherwise would not be amenable through lateral cephalograms.

2.4.2 Benefits of 3-dimensional images in clinical use

Orozco had found that different diagnostic records can lead to different orthodontic treatment plans (Orozco, J., 2010). In continuation of this study, Lee continued to study orthodontic treatment with 3-dimensional images using 3dMD system. A qualitative analysis was completed to compare the clinician's perspective of the soft tissue changes before and after orthodontic treatment using 2-dimensional and 3-dimensional images. Many orthodontists were surveyed and agreed with the advantages of the use of 3-dimensional images in its representations of the shadow, contour, and depth of the soft tissues which cannot be captured in a 2-dimensional image (Lee, P., 2013). Although most clinicians have a higher comfort level with the use of conventional photogrammetry, an increased exposure and willingness to embrace the new technology of the 3-dimensional images will surely help advance the field of orthodontics.

2.5 Soft tissue changes with orthodontic treatment

2.5.1 Soft tissue changes observed on 2-dimensional cephalogram in orthodontic treatment with extractions

Soft tissue changes in orthodontic treatment with extractions have been primarily studied and measured from the 2- dimensional lateral cephalogram. The radiographs were taken before and after orthodontic treatment and the linear and angular measurements were compared. The linear measurements in the perioral region generally are used to measure the protrusion or retrusion of the lips, and the angular measurements are used to measure the nasolabial angle and mentolabial angles. Many studies support the finding of retrusion of the upper and lower lip and increased in nasolabial angle with orthodontic treatment with extractions (Finnoy, J., et al., 1987; Drobocky, O., et al., 1989; Al-Sibaie, S., et al., 2014; de Alemdia-Pedrin, R., et al., 2009; Janson, G., et al., 2007; Kinzinger, G., et al., 2009; Upadhyay, M., et al., 2012; Weyrich, C. et al., 2009). In a systematic review, the upper lip retraction ranged from 2-3.2 mm, and the lower lip retraction ranged from 2-4.5 mm and the soft tissue were not dramatically changed by premolar extractions (Leonardi, R., et al., 2010). But, these studies do not consider the effects of other facial structures that are in the mid-face including the depth and width changes that are unavailable to obtain from 2-dimensional films. The question remains, are the changes observed in the 2-dimensional cephalogram the true changes that occur?

To determine the difference of changes noted, in 2- dimensional cephalograms and 3-dimensional optical images of pre and post orthodontic treatment patients were compared. While the cephalogram showed no significant difference in the lip in relationship to the E-plane, there was 3-5 mm difference in the upper lip position in reference to the forehead when comparing changes of pre and post treatment with 3-dimensional images. In addition, a 6° of difference in the labiomental fold increase in cephalometric changes were not noted in the 3-dimensional view. The 3- dimensional analysis provided a diverse assessment of the face in the effects of orthodontic treatment compared to the 2- dimensional cephalograms and would be a strong benefit when evaluating soft tissues (Ismail, S., et al., 2002). To use more than one analysis to observe and assess the changes can increase our diagnostic value as well as lead to a realistic and predicted results with orthodontic treatment (Bishara, S., et al, 1988).

2.5.2 Soft tissue changes with orthodontic treatment in 3-dimensional images

Temple University Kornberg School of Dentistry, Department of Orthodontics has been a pioneer of 3-dimensional imaging. From the 3-dimensional wire frame mesh by Michael Nuveen, to structured light by Nyguen, and the Craniofacial Imaging and Animation system by Slattery and Tuncay, Temple University has played an integral part in advancing 3-dimensional imaging (Nuveen, M., 1996; Nguyen, C., 1998, 2000; Slattery, J., 2001). In continuation to these studies, soft tissue changes with orthodontic treatment were evaluated.

Croft was one of the first to superimpose the pre and post 3-dimensional images to determine the changes with orthodontic treatment at Temple University (Croft, D., 2009). Following his superimposition methods, soft tissue changes were evaluated in extraction and non-extraction patients with different mandibular plane angles. Two studies found minimal changes in the soft tissues between both treatment types in different mandibular plane angles, including high, average and low mandibular angle groups (Franklin, B., 2009; Papasikos, J., 2013). However, Uffner in the contrary, found significant differences in the soft tissue changes between non-extraction and extraction high angle subjects and less soft tissues changes noted in low mandibular angle groups (Uffner, N., 2013). Other perioral structures including the commissures, nasolabial angle, and mentolabial fold had confounding results and need further investigation.

CHAPTER 3

AIMS OF THE INVESTIGATION

The principal aims of this investigation was to determine if the volumetric consequences of extraction treatment are different in the thin and thick facial tissue patients. We studied these soft tissue changes, specifically, in the region of the nasolabial fold. We had chosen to focus in this region due to significant paucity of 3D information on nasolabial depth changes with any orthodontic treatment plan. In addition to volumetric changes, we chose to also explore patterns of topographical soft tissue changes in these Class I subject treatments with extractions. We were agnostic if volumetric measurements are portents of topography.

CHAPTER 4

MATERIALS & METHODS

4.1 Study sample

The research design was submitted to the Temple University Institutional Review Board (IRB) and deemed exempt. All subjects were sampled from the Podray Orthodontic clinic of Temple University, Maurice H. Kornberg School of Dentistry in Philadelphia, PA, who had completed their orthodontic treatment by previous orthodontic residents with an attending faculty. Patient demographic can be found in Appendix A. Fourteen patients were selected based upon several criteria:

- Class I skeletal classification by their ANB value (0˚ and 4.4˚) and/or from Wits measurement (-1 to +1) from cephalometric tracings
- 4 premolar extractions
- initial and final 3D images (.tsb files)
- initial and final cephalogram taken at Podray clinic
- completion of orthodontic treatment by June 30th, 2017

4.2 Image acquisition

The 3dMD face system (3dMd, Atlanta, GA) was used to capture the 3-dimensional images of each subject before and after their orthodontic treatment. Images captured from ear-to-ear and from the clavicle to the top of the head, for each patient. These photographic images the patients captured in their natural head position in repose and upon smiling.

4.3 Image manipulation

All the images taken were saved as .tsb files on LG 64 bit operating system (Intel Core i5-2400 CPU @ 3.10 GHz, Display-NVIDIA GeForce GT440) running on Windows 7 Professional (Microsoft Corp, Redmond, WA). 3dMD vultus (3dMD, Atlanta, GA) software was used to manipulate and superimpose the images.

4.4 Superimposition

The superimposition procedure was adapted from previous studies from Temple University (Croft, D., 2009; Franklin, B., 2009, Papasikos, J., 2013). Similar to Papasikos studies at Temple University, 3dMD Vultus program was used for image manipulation. The pre treatment and post treatment were initially superimposed to best fit (Figure 2). These images were then registered using the most accurate and stable soft tissue areas in a T-shaped area including nasal bridge and forehead (Croft, D., 2009) as seen in Figure 3.

Figure 2. Superimposition of best fit shown in profile view

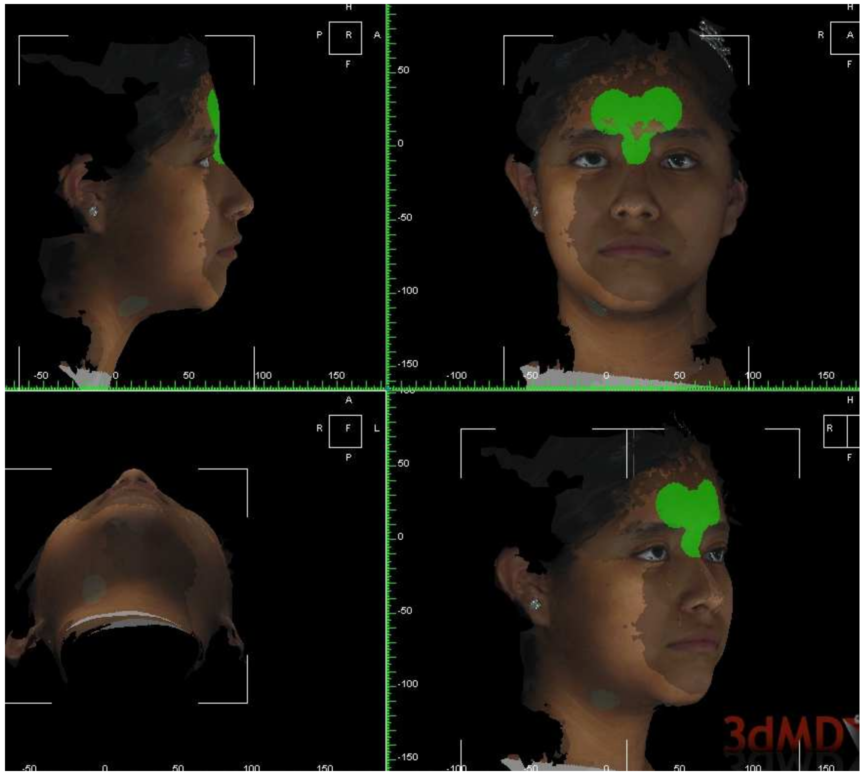


Figure 3. Registration on nasal bridge and forehead

4.5 Topographical map

Using 3dMD vultus software, the pre and post-treatment 3dMD images were used to construct a color histogram. The pre-treatment facial surface image was used as the reference and the post-treatment was used as the difference surface. The color-coded map indicates the direction and magnitude of soft tissue changes.

4.6 Cephalometric analysis

Cephalometric radiographs were traced on Dolphin imaging software to measure the two-dimensional soft tissue changes of pre- and post-treatment. The upper lip thickness was measured from the vermillion border of the lip to the labial surface of the maxillary central incisor. Ricketts analysis E plane was also measured for the upper lip pre- and post-treatment.

4.7 Error analysis

All superimpositions and measurements were completed by one investigator. Three superimpositions were completed in the 3dMD vultus software and the RMS value in the color histogram was used to verify repeatability. For each superimposition, the volumetric analysis was also completed three times for repeatability. In addition, total of three points (subnasale, right and left commissures) were selected out of the nine points for linear comparisons to confirm the volumetric changes (Figure 4). Intra rater reliability was performed for each superimpositions as well as in between superimpositions.

Cephalometric radiographs were also traced three times and intra rater reliability was performed.

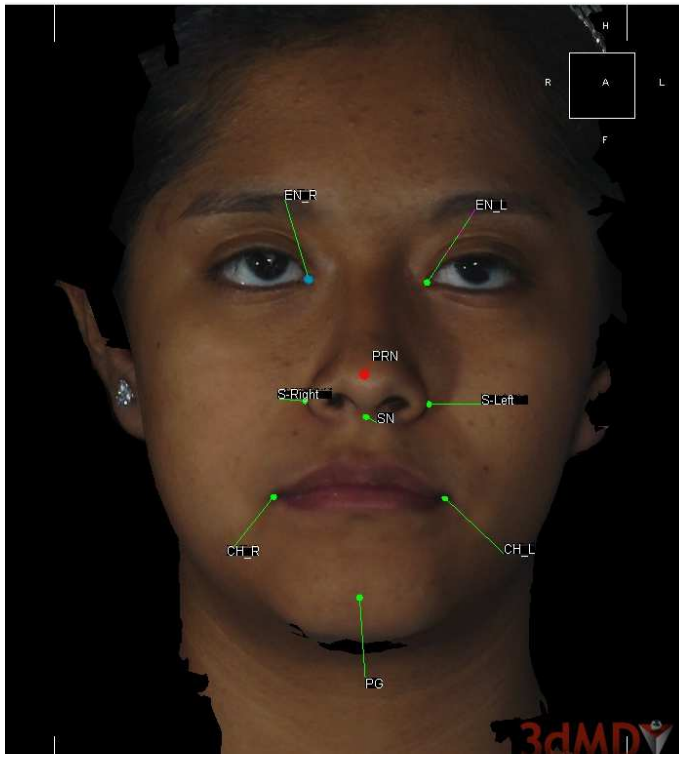


Figure 4. Landmarks used for Linear measurements (EN_R= Endocanthion Right, EN_L= Endocanthion Left, PRN= Pronasale, SN= subnasale, S-Right= Subnasale Right, S-Left= Subnasale Left CH_R= right commissure, CH_L= left commissure, PG= Pogonion)

4.8 Quantitative analysis

To quantify 3-dimensional soft tissue differences around nasolabial fold, volumetric changes (cc) were measured using the two surfaces tool in 3dMD vultus. The volume changes of the nasolabial fold region were measured pre- and post-treatment for each patient. To measure the volumetric changes surrounding the nasolabial fold, a triangle was selected in the lateral and medial regions of the nasolabial fold (Figure 5). The selected points for the triangle lateral to the nasolabial fold were as follows: the most lateral border of the ala of the nose in the frontal view, the most lateral border of the pupil parallel to the plane drawn at previously selected most lateral border of the ala of the nose, and the intersection of the ipsilateral commissure plane with perpendicular plane drawn in reference to the lateral border of the pupil. The selected points for the triangle medial to the nasolabial fold were as follows: the most center and inferior border of the subnasale in the frontal view, the most inferior and lateral of the alar base, and the ipsilateral commissure.

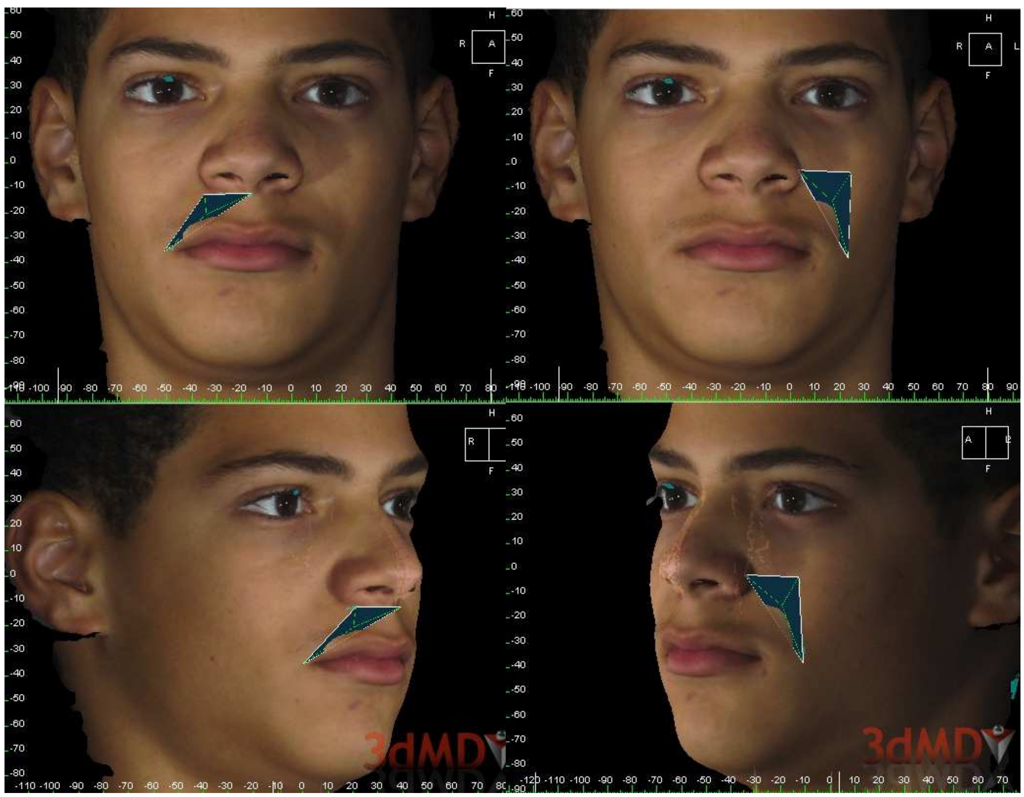


Figure 5. Triangles medial and lateral to the nasolabial fold used to measure volumetric changes. Top left= Right In, Top right= Left out, Bottom right= Right In, Bottom left= Left out

Cephalometric radiographs were used to measure the soft tissue thickness and changes pre- and post-treatment. The upper lip to U1 measurement was used to measure thickness and the U-lip to Ricketts E-plane was used to measure the protrusion or retrusion of the upper lip in relationship to the Ricketts line. In addition, SN-U1 was measured pre- and post-treatment using the lateral cephalometric radiographs to determine the retraction of the upper incisors. All the measurements were completed electronically on Dolphin.

4.9 Qualitative analysis

The color histogram was used for the qualitative analysis. The color-coded map (Figure 6) was used to determine the direction and magnitude of changes in the soft tissues. The warmer colors, such as purple, pink and red, represents a positive change or a change in the anterior direction. The cooler colors, such as turquois and green, represent a negative change or a change in the posterior direction. The shades of blue in the middle indicates no changes. The color changes are used to describe the qualitative changes that are seen around the nasolabial fold pre- and post-treatment. The degree of change in color histogram was measured by correlating change in colors to symbols ranging from (+++) to indicate change in anterior direction and (---) to indicate change in the posterior direction. This method was applied to describe the changes in seven specific regions: subnasale, upper and lower lip, right and left commissures, and the soft tissue medial and lateral to the nasolabial fold.

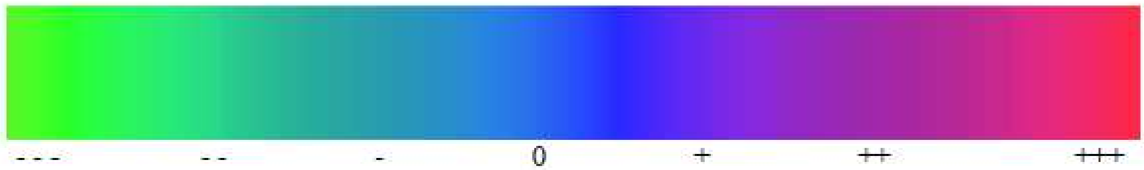


Figure 6. Color histogram map

4.10 Statistical Analysis

Data analysis was performed using SPSS software. The Spearman's rho test was used for lip thickness, lip retraction, and incisor retraction cephalometric measurements in relationship to volumetric soft tissue changes medial and lateral to the nasolabial fold. Regression analyses were completed controlling for age, gender, and ethnicity. Differences with a $P < .05$ were considered statistically significant.

CHAPTER 5

RESULTS

5.1 Quantitative analysis

The quantitative volumetric measurement (cc) analyses of pre- and post-treatment triangles medial and lateral to the nasolabial fold (illustrated previously in Fig 5), were completed for each subject. Three measurements were completed for each superimposition for each subject. Each row in the table below represents the mean of from all nine measurements from all three superimpositions. All four measurements of the soft tissue, medial and lateral to the nasolabial fold, showed similar change for each subject (Table 1). It should be noted, that while the volumetric measures show large variance in between subjects ranging from -86 cc to +247 cc, the four measurements for each within subject data displayed no detectable differences. Complete raw data are presented in Appendix B.

Table 1. Mean volumetric change (cc) medial and lateral to right and left nasolabial fold for all three superimpositions. Colors represent categorization by their magnitude of change (high=red, moderate=blue, minimal=white).

Subject	Left_Lat	Left_med	Right_med	Right_Lat
1	1.622	1.610	1.57	1.622
2	-23.809	-23.754	-23.806	-24.845
3	-7.871	-7.852	-7.754	-8.055
4	-12.85	-1.298	-1.338	-1.336
5	1.359	1.353	1.394	0.762
6	-86.-057	-86.157	-86.231	-86.391
7	69.192	69.303	69.333	69.389
8.	91.126	91.015	91.052	90.774
9	246.548	246.480	246.498	246.574
10	36.851	36.893	36.784	36.887
11	0.091	-0.127	-0.111	-0.047
12	0.026	-0.014	-0.066	0.054
13	-0.105	-0.038	-0.049	-0.103
14	3.452	3.459	3.542	3.439

In the cephalometric radiograph measurements, the upper lip thickness and upper lip position to the Ricketts E-plane were measured (Table 2). The change in lip thickness ranged from -5.7mm to 3mm from pre- to post-treatment. The change in upper lip position to E-plane ranged from 0.2 to 4.17 mm change. Complete raw data are presented in Appendix C.

Table 2. Cephalometric soft tissue measurements. Color coded to represent three volumetric groups (high=red, moderate=blue, minimal=white).

Subject	U-lip thickness Pre-tx	U-lip thickness Post-tx	Change in Upper lip thickness	U-lip to Ricketts Pre-tx	U-lip to Ricketts Post-tx	Change in Upper to Ricketts
1	11.2	11.1	0.1	-0.63	-4.03	3.4
2	11.23	8.23	3.0	-1.03	-3.43	2.4
3	9.77	12.4	-2.63	2.87	2.03	0.84
4	11.9	12.2	-0.3	2.53	-0.67	3.2
5	13.73	13.37	0.36	3.72	0.03	3.69
6	15.7	17.7	-2.0	0.63	-0.83	1.46
7	10.3	13.3	-3.0	-2.4	-2.6	0.2
8	10.46	11.97	-1.51	0.43	-1.77	2.2
9	11.6	14.5	-2.9	3.4	2.37	1.03
10	11	13.2	-2.2	1.33	0.27	1.06
11	12.77	18.47	-5.7	8.17	7.03	1.14
12	10.27	13.67	-3.4	-1.33	-3.5	2.17
13	10.63	10.5	0.13	4.7	0.53	4.17
14	13.67	14.57	-0.9	1.83	-0.43	2.26

Table 3. Cephalometric measurement for upper incisor. Color coded to represent three volumetric groups (high=red, moderate=blue, minimal=white).			
Subject	**SN-U1 pre-tx (˚)**	**SN-U1 post-tx (˚)**	**Change in SN-U1 (˚)**
1	119.7	99.7	20
2	145.5	110.9	34.6
3	116.4	105.7	10.7
4	114.6	92.4	22.2
5	122.7	101.2	21.5
6	101.2	102.2	-1.0
7	102.6	103.0	-0.4
8	119.8	105.0	14.8
9	99.6	100.9	-1.3
10	117.2	116.3	0.9
11	117.5	98.6	18.9
12	120.2	112.7	7.5
13	115.2	102.6	12.6
14	123.7	118.4	5.3

In addition to the soft tissue measurements, dental measurement of SN-U1 were completed from the cephalometric radiographs (Table 3). The change in incisor movement ranged from 1.3˚ protraction to 34.6˚ retraction to of the upper incisors. Complete raw data are presented in Appendix D.

There were variable results for pre- and post-treatment change in upper lip thickness and change in upper lip to Ricketts E-line. The greatest positive volumetric change in the soft tissue surrounding the nasolabial fold, indicating fullness in the nasolabial fold area, was observed in subject 9 with 247.253cc. Subject 9 had a negative change in upper lip thickness of 2.9 mm indicating thickening of the lips post-treatment and a positive change of 1.03 mm upper lip to Ricketts E-line indicating upper lip retraction. The upper incisors had a positive change of 1.3˚ indicating proclination of upper incisors post-treatment.

The least volumetric change in the soft tissue surrounding the nasolabial fold was observed in subject 12 with 0.011 cc, and also in subject 13 with change of -0.018 cc. Subject 12 had a negative change in the upper lip thickness of 3.4 mm indicating thickening of the lips post-treatment and a positive change of 2.17 mm upper lip to Ricketts E-line indicating upper lip retraction. Upper incisors of subject 12 had positive change of 7.5˚ indicating uprighting of upper incisors post-treatment. Subject 13 had positive change in upper lip thickness of 0.13 mm indicating thinning of the lips post-treatment and a positive, and greatest change in upper lip to Ricketts E-line of 4.17 mm indicating greatest amount of retraction of the upper lips in reference to the E-plane.

The subject with the greatest negative volumetric change, indicating the greatest retraction of the soft tissues near the nasolabial fold, was subject 6 with a change of -86.941 cc. Subject 6 had a negative change in the upper lip thickness of 2.0 mm indicating thickening of the lips post-treatment, and a positive change of 1.46 mm upper lip to Ricketts E-line indicating upper lip retraction. Upper incisors of subject 6 had negative change of 1.0˚ indicating proclination of the upper incisors post-treatment.

The subject that had the greatest change in upper lip thickness pre- and post-treatment was subject 11 with a negative change of 5.7 mm indicating increase in thickness post-treatment. In response to the upper lip to Ricketts E-line however, there was a retraction of the upper lip of 1.14 mm in relationship to the Ricketts E-plane. This subject also had a change of 18.9˚ uprighting of the upper incisors. This subject displayed minimal change in the volumetric soft tissue surrounding nasolabial fold of 0.119 cc.

The subject with the greatest change in upper incisor angulation was subject 2 with a positive change of 34.6˚ indicating uprighting of the upper incisors. This subject also had a 3.0 mm change in upper lip thickness indicating decrease in lip thickness post-treatment, and a 2.4 mm positive change in upper lip to Ricketts E-plane indicating upper lip retraction post-treatment.

5.2 Statistical Analysis

Data analysis was performed using SPSS software. Spearman's *rho* analysis of pre-treatment upper lip thickness and its changes, pre-treatment upper lip to E-plane and the difference in change, and upper incisor retraction in reference to SN and the difference in change were compared to the volumetric changes of soft tissue surrounding the nasolabial fold. When all the correlation analyses were completed, no statistical significance could be detected ($p > 0.05$). Regression analysis of nasolabial volume and thickness were also run, controlling for age, gender, and race. There were no statistical significances.

Thus, the null hypothesis cannot be rejected. There was no direct correlation of volumetric consequences of extraction treatment that are different in the thin or thick facial tissue patients.

5.3 Error Analysis

For reliability testing, intraclass correlation was completed. Initially, the superimpositions RMS values were evaluated for their repeatability. The intraclass correlation was high ($R=0.973$). For volumetric analysis, three separate superimpositions were completed, and three measurements were taken per superimposition. Total of 9 measurements were taken for one variable. These were calculated for intraclass correlation and the measurements were high ($R=0.999$). Similarly, the intraclass correlation for three cephalometric measurements for the lips and teeth were completed with a high correlation ($R=0.998$).

5.4 Qualitative analysis

The qualitative analyses of pre- and post-treatment of color histogram were completed for each subject. The superimpositions were obtained from the quantitative analyses. The surface difference statistics represents the RMS value, a root mean square, that is calculated to define the error over the registered points. Lower value is more ideal but a low value is not indicative of a proper alignment.

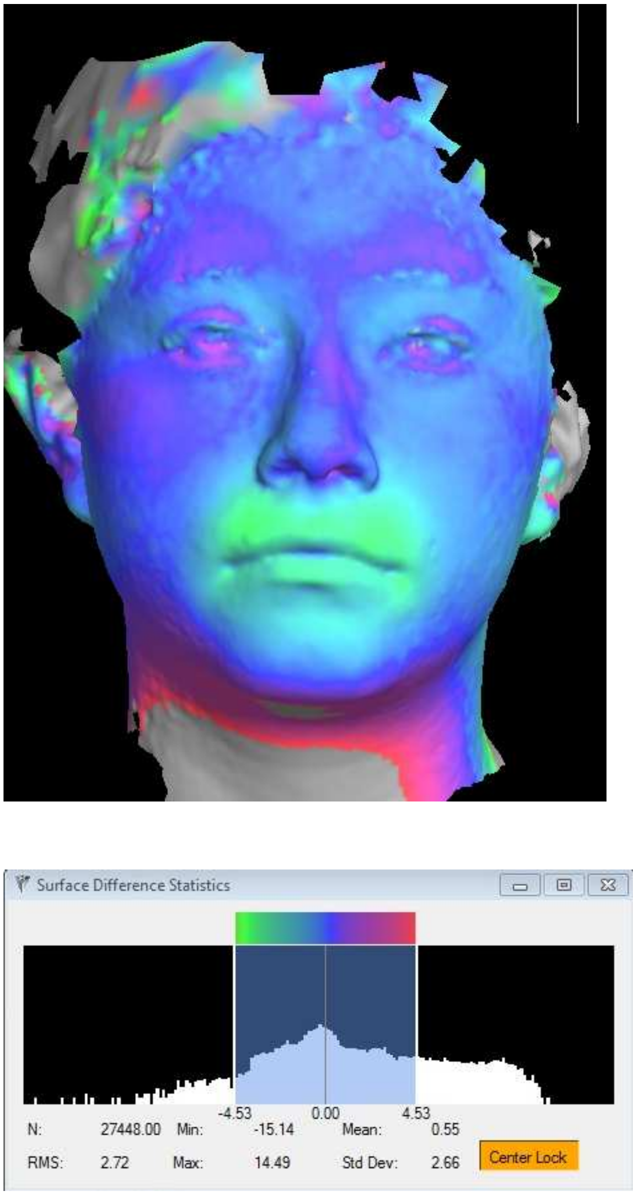


Figure 7. Subject 1 Color Histogram. The upper lip (---), lower lip (---), right and left commissures (--), and the soft tissue medial to the nasolabial fold (---) were retracted. The subnasale (0) and soft tissue lateral to nasolabial fold (0) had no changes.

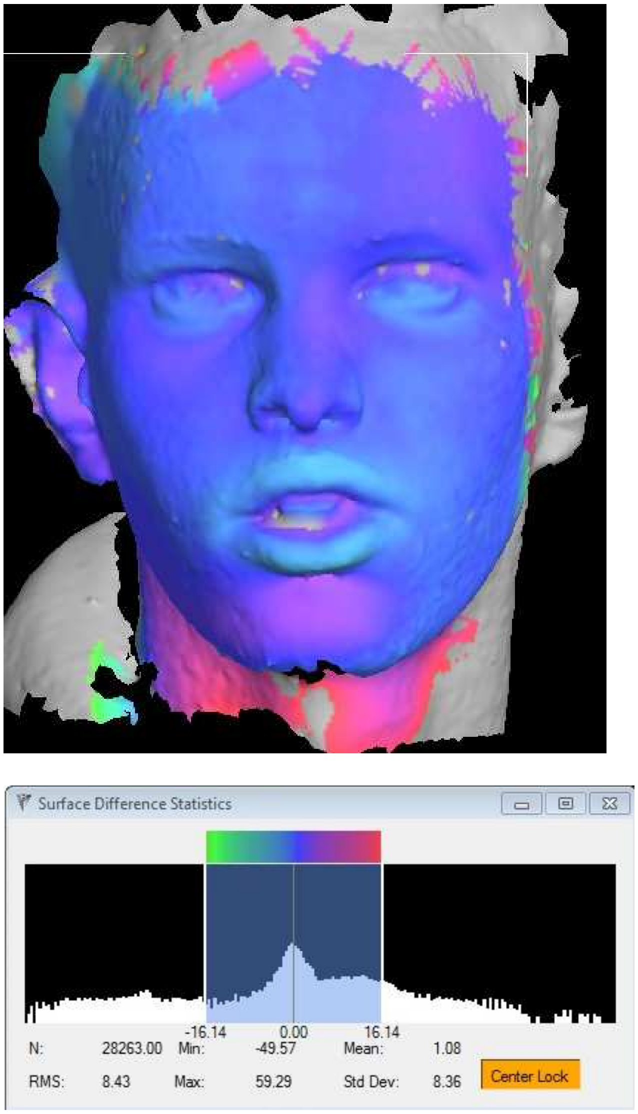


Figure 8. Subject 2 Color Histogram. The soft tissue medial and lateral to the nasolabial fold (+) had came slightly forward. The subnasale (0) had no change. The left and right commissures (-), upper and lower lip (-) had minimal negative changes.

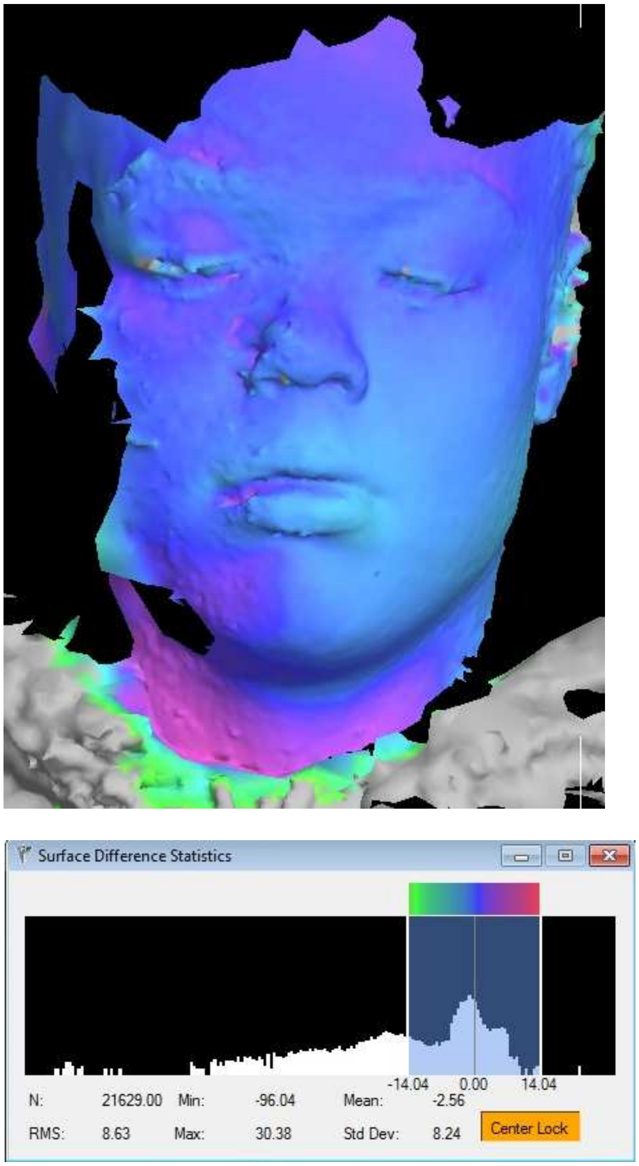


Figure 9. Subject 3 Color Histogram. The upper (-) and lower lips (-), right and left commissures (-) were retracted. The subnasale (0), soft tissue both medial and lateral to the nasolabial fold (0) had no changes.

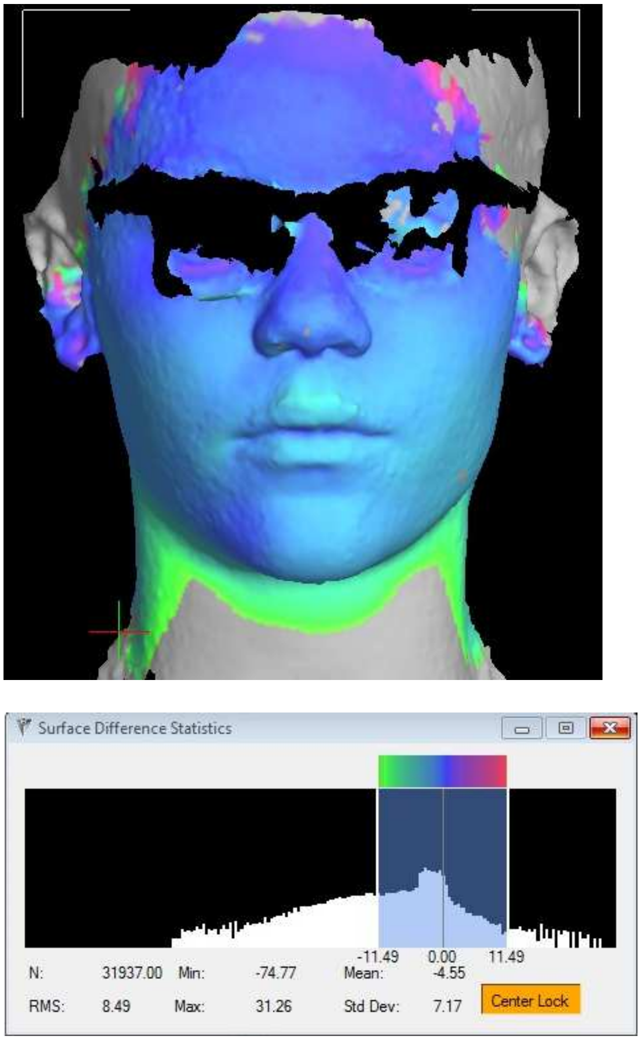


Figure 10. Subject 4 Color Histogram. The upper lip (--) and lower lip (-) were retracted. The subnasale (0), right and left commissures (0), and soft tissue medial and lateral to the nasolabial fold had no changes.

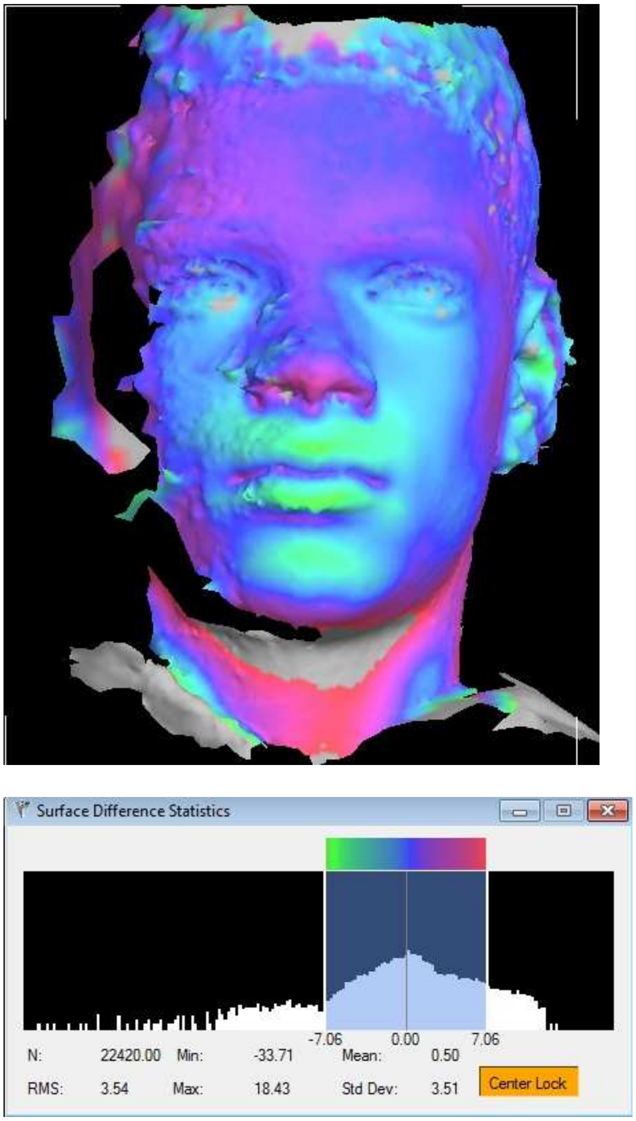


Figure 11. Subject 5 Color Histogram. The upper lip and lower lip (---), soft tissue medial to nasolabial fold (---) and lateral to the nasolabial fold (-) were retracted. The subnasale (0) and right and left commissures (0) had no changes.

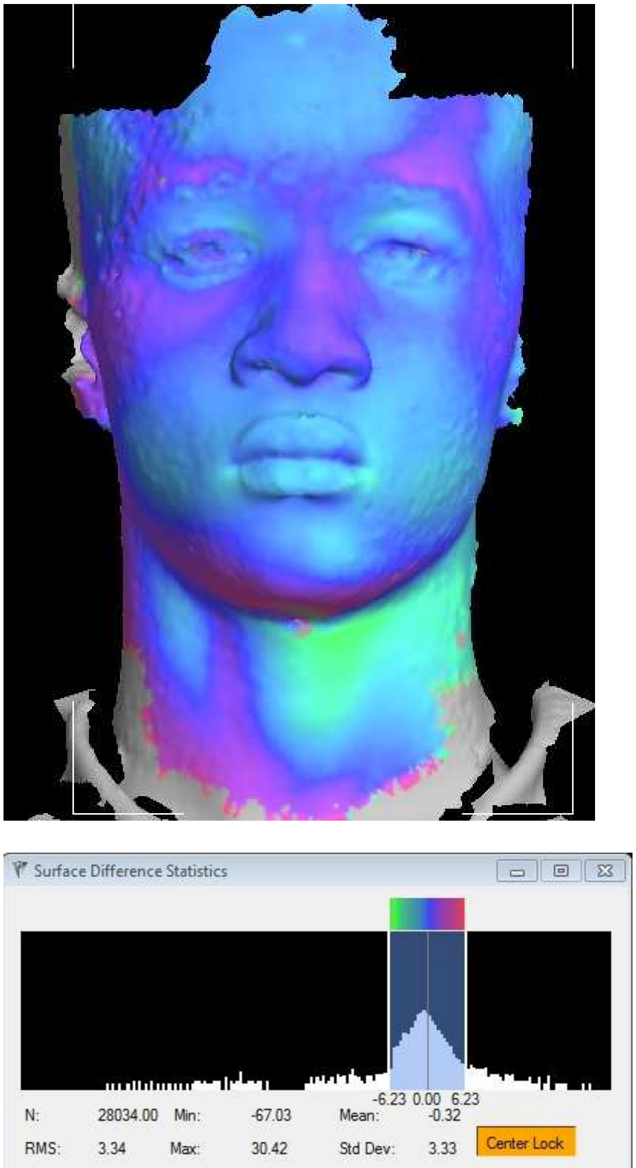


Figure 12. Subject 6 Color Histogram. The right and left commissures (--), upper and lower lip (-) showed negative changes. The soft tissue medial and lateral to the nasolabial fold (0) and subnasale (0) showed no changes.

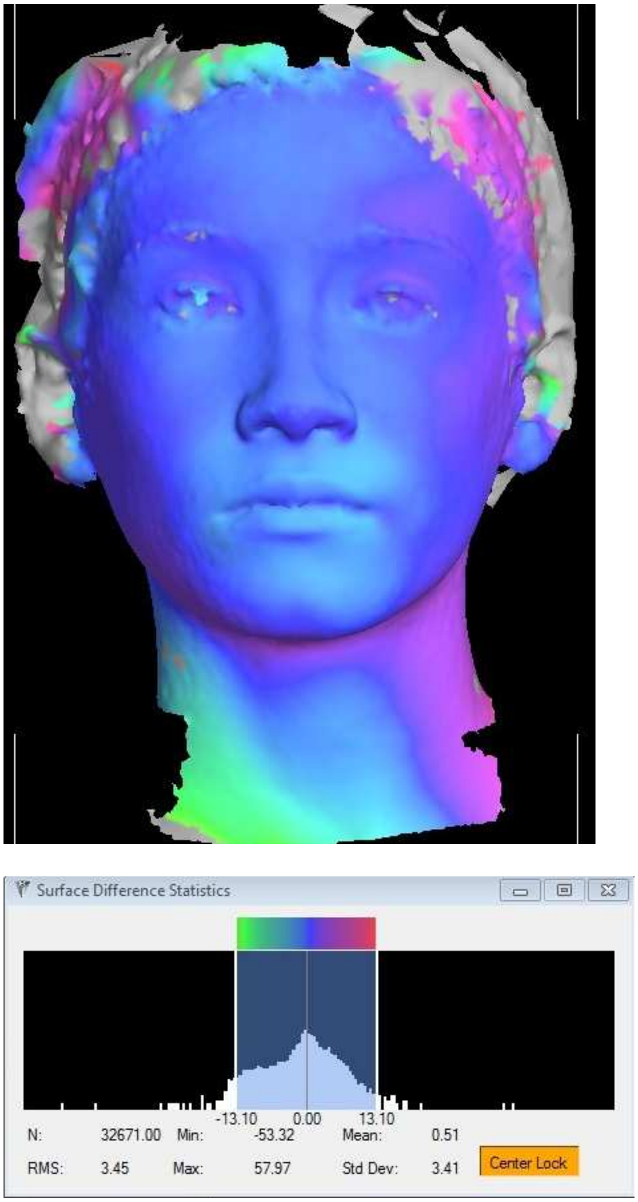


Figure 13. Subject 7 Color histogram. The soft tissue medial to the nasolabial fold (-) showed negative changes. The right and left commissures (0), the soft tissue lateral to nasolabial fold (0), subnasale (0), upper lip (0) and lower lip (0) showed no changes.

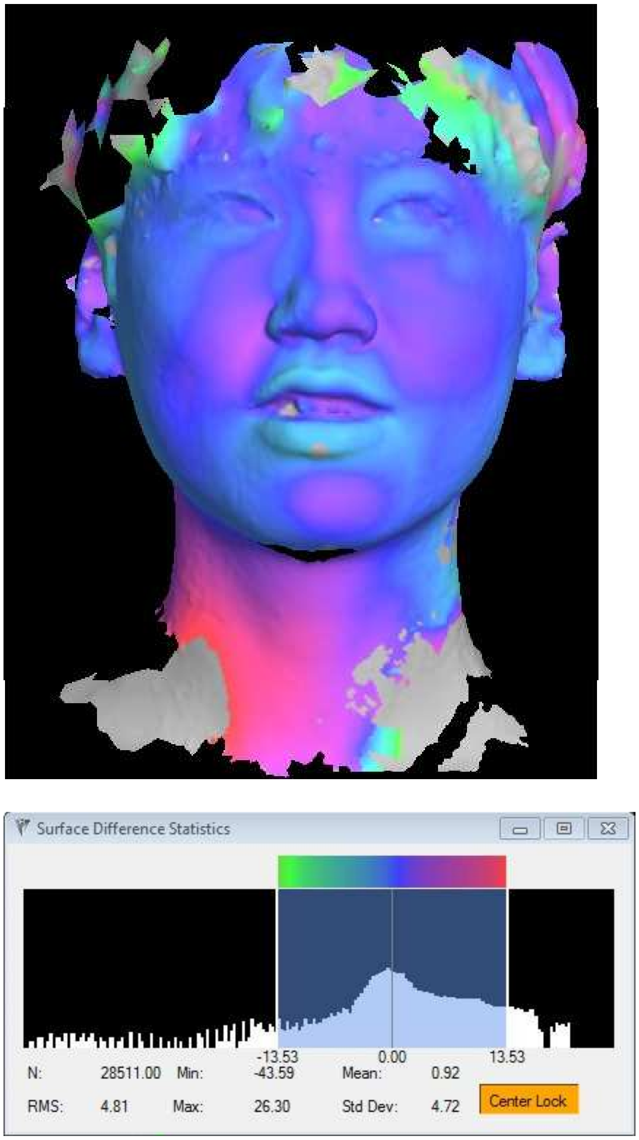


Figure 14. Subject 8 Color histogram. The upper and lower lip (-) and right and left commissures (-) were retracted. The soft tissue lateral to nasolabial fold (++) came forward. The soft tissue medial to the nasolabial fold (0), subnasale (0) had no changes.

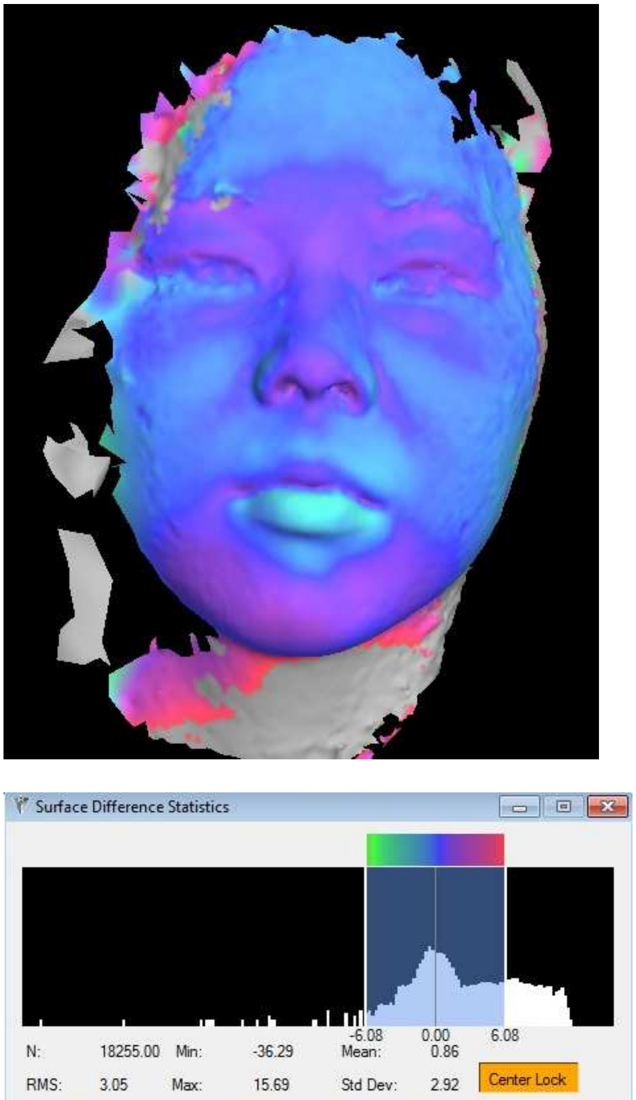


Figure 15. Subject 9 Color Histogram. The lower lip (--) were retracted. The subnasale (+), soft tissue lateral to the nasolabial fold (+) and right commissure (+) came forward. The upper lip (0), soft tissue medial to the nasolabial fold (0) and left commissures (0) had no changes.

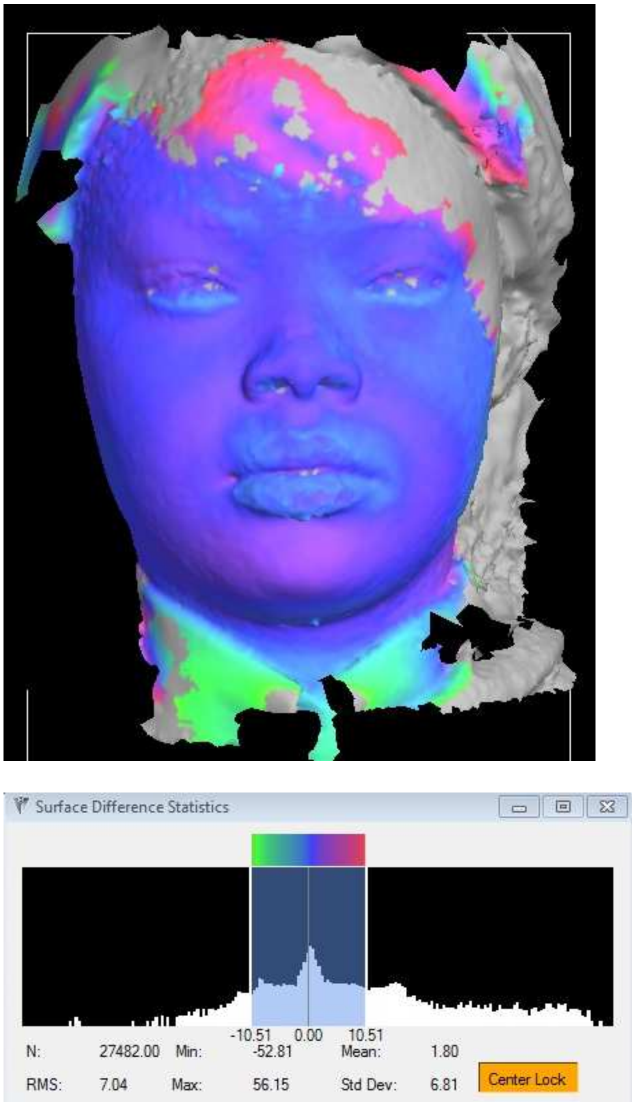
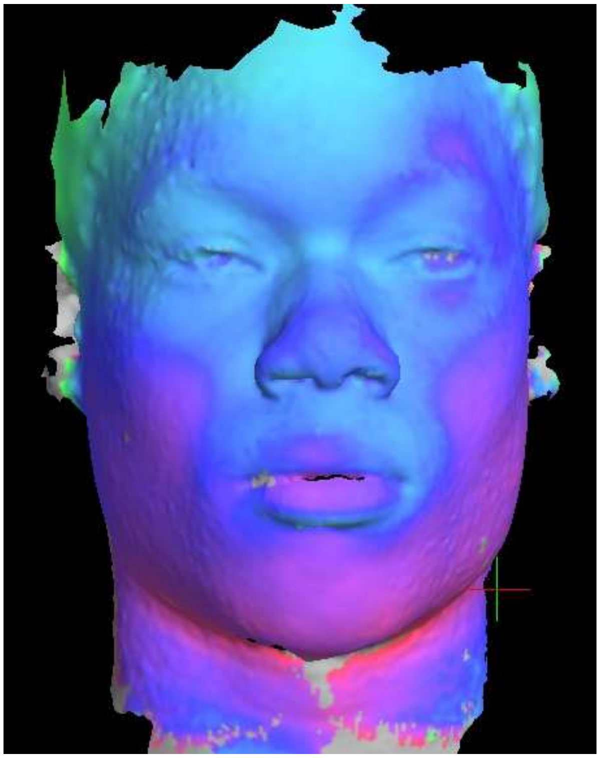


Figure 16. Subject 10 Color Histogram. The soft tissue lateral and medial to the nasolabial fold (++), subnasale (++), upper and lower lip (+), and right commissure (+) came forward. The left commissures (0) had no changes.



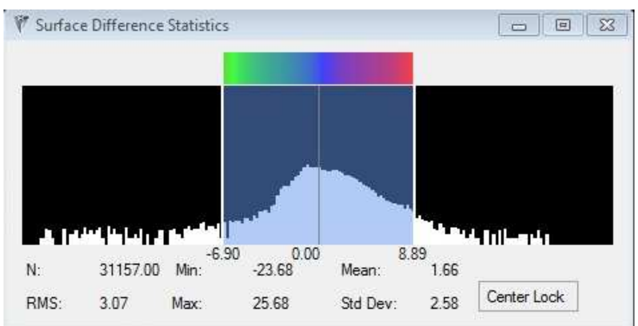


Figure 17. Subject 11 Color Histogram. The soft tissue medial to nasolabial fold (-) were retracted. The upper lip (+) and lower lip (++) and soft tissue lateral to nasolabila fold (+) came foward. The subnasale (0) and right and left commissures (0) had no changes.

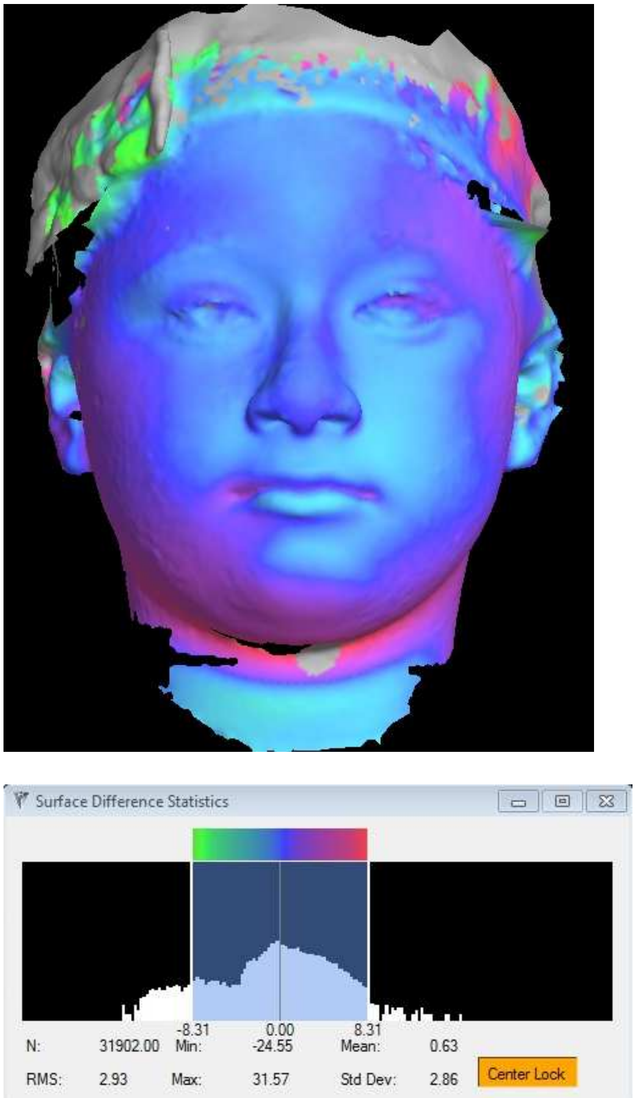


Figure 18. Subject 12 Color Histogram. The upper and lower lip (-), soft tissue medial (-) and lateral (-) to the nasolabial fold were retracted. The right and left commissures (++) came forward. The subnaslae (0) had no change.

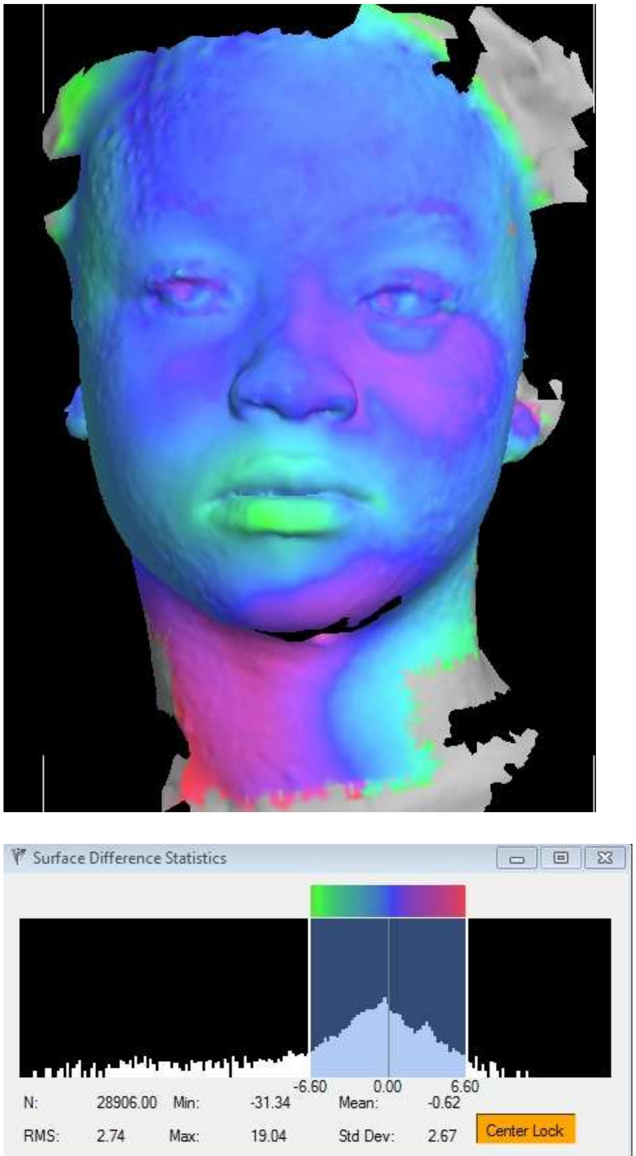


Figure 19. Subject 13 Color Histogram. The upper (---) and lower lip (---) and right (---) and left (---) commissures, soft tissue medial to the nasolabial fold (--) were retracted. The left soft tissue lateral to the nasolabial fold (+) came forward slightly. The right soft tissue lateral to the nasolabial fold (0) and subnasale had no changes.

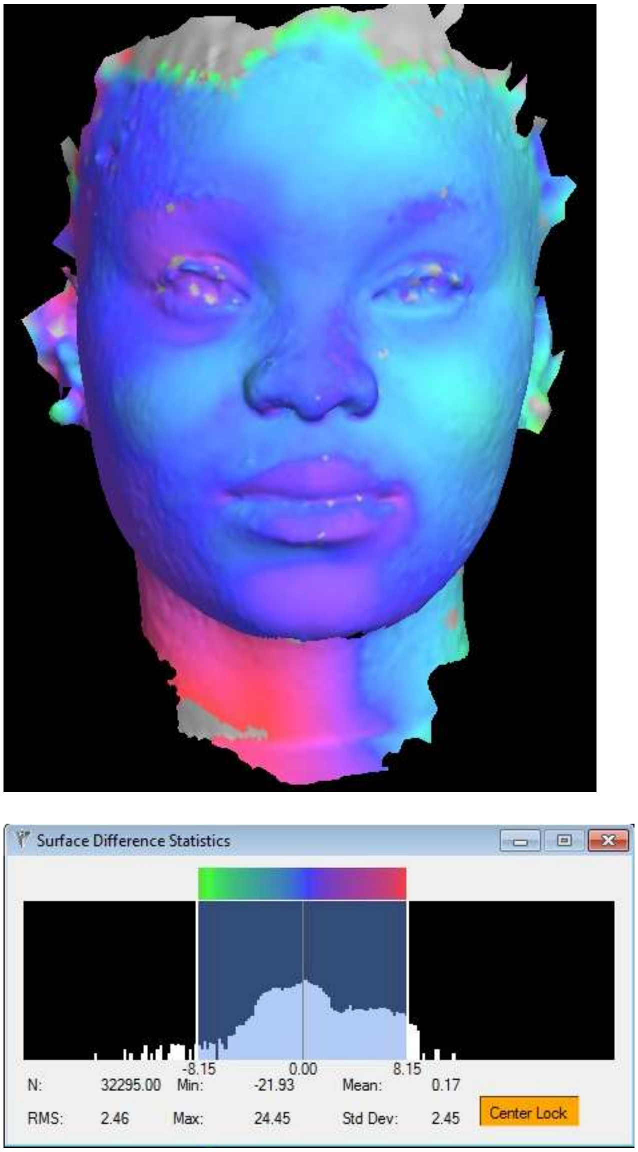


Figure 20. Subject 14 Color Histogram. The soft tissue lateral to the nasolabial fold (-) retracted. The upper and lower lips (++) along with right and left commissures (++) came forward. The subnasale and soft tissue medial to the nasolabial fold (0) remained unchanged.

Table 4. Qualitative Changes. Magenta represents positive(+) change, blue color represents negative(-) change, 0 represents no change.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Subnasale	0	0	0	0	0	0	0	0	+	++	0	0	0	0
ST-lateral	0	+	0	0	---	0	0	++	+	++	+	-	+/0	-
ST- medial	0	+	0	0	---	0	-	0	0	++	-	-	--	0
Upper lip	---	-	-	--	---	-	0	-	0	+	+	-	---	++
Lower lip	---	-	-	-	---	-	0	-	--	+	+	-	---	++
R commissure	--	-	-	0	0	--	0	-	+	+	0	++	---	+++
L commissure	--	-	-	0	0	--	0	-	0	0	0	++	---	++

The qualitative analysis showed variability for each subject. In general, growth was noted mostly in the areas of the lower borders of the mandible. Also noted was asymmetric soft tissue changes. There was no consistency in qualitative and numeric data. Changes exhibited by the upper and lower lips did not translate to same changes in the soft tissues medial and lateral to the nasolabial fold (Table 4).

CHAPTER 6

DISCUSSION

Previous studies at Temple University Kornberg School of Dentistry, Podray clinic have evaluated changes in perioral structures including the commissures, nasolabial angle, and mentolabial fold with orthodontic treatment (Croft, D., 2009; Franklin, B., 2009; Papasikos, J., 2013; Uffner, N., 2013). Also, numerous studies were published that identified the soft tissue changes relative to the hard tissue changes in response to orthodontic treatment. They were all in 2-dimensional lateral cephalograms (Bishara, SE., 1998; Bishara, SE., 2000; Finnoy, J., et al., 1987; Drobocky, O., et al., 1989; Al-Sibaie, S., et al., 2014; de Alemdia-Pedrin, R., et al., 2009; Janson, G., et al., 2007; Kinzinger, G., et al., 2009; Subtelny, D., 1961; Upadhyay, M., et al., 2012; Weyrich, C., et al., 2009). There was a lack of information in 3-dimensional changes, especially, in volumetric changes. In this study, the aim was to identify the 3-dimensional volumetric changes of nasolabial fold in four premolar extraction Class I subjects, as influenced by the thickness of the soft tissues.

Data collected in this study, revealed a wide variability in the soft tissue changes around the nasolabial fold for all subjects. In the quantitative results, the volumetric changes in the soft tissue surrounding the nasolabial fold had no correlation to the upper lip thickness pre- and post-treatment, the upper lip to Ricketts E-plane, or to the incisor proclination pre- and post-treatment. In a previous study by Oliver, there was a strong correlation to soft tissue changes to the hard tissue changes in subjects with thin lips (Oliver, BM., 1982). Similarly, we had speculated that a thinner soft tissue in comparison to thicker soft tissue subjects would have greater soft tissue changes after premolar extraction with orthodontic treatment. Positive volumetric changes in the surrounding soft tissues around the nasolabial fold would be indirectly correlated to the deepening of the nasolabial fold. In contrast, we found no significant correlation of the volumetric changes of soft tissues medial and lateral to the nasolabial fold compared to the soft tissue thickness and its changes pre- and post-treatment obtained from the cephalometric measurement. There was also no significant correlation between the amount of change in pre- and post- treatment lip thickness and volumetric change medial and lateral to the nasolabial fold within the limitations of this study.

One of the initial tasks of our study was to narrow down the skeletal type of the subjects that will be included in this study. The selection criteria used in this study for the skeletal I malocclusion analysis was by either Steiner's or Wits. The Steiner's measurements factor in A point and B point in relationship to the anterior cranial base, at nasion, while the Wits analysis measures A point and B point in reference to the occlusal plane. Therefore, while some subjects may be Class I skeletal with Steiner measurement, they may not be Class I with Wits analysis and vice versa. This discrepancy indicates non-homogeneity in the Class I malocclusion subjects. Not all Class I malocclusions are the same. Perhaps, a classification in which the subjects would have to fulfill both Steiner and Wits criteria for Class I malocclusion would have produced a more homogeneous group of subjects. Of course, such study will have its own problems. For example, narrowing the skeletal classification would reduce the number of sample size even further than our study.

The variability in the quantitative analysis can also be contributed to the wide range in age. In the 14 subjects chosen, the age range was 12-26 years old. The wide range in the age population in this subject group could have led to the variable result. The retraction of soft tissue changes with age, especially the upper lip, has been well studied and observed in 2-dimensional studies (Bishara, SE., et al., 1998; Ghafari, J., et al., 1987; Formbly, WA., et al., 1994). A 3-dimensional study by Kau also observed soft tissues with age with decreased volume lateral to the nasolabial fold or flatter cheeks with growth (Kau, C., 2008). Another study using magnetic resonance imaging (MRI) found most dramatic changes in the temporal, infraorbital, and lateral and medial cheek areas in ages of 30 to 60 (Wysong, A., et al., 2013). In our study, Spearman's rho analysis was used due to the small sample size, but our results did not find statistically significant correlation between volume changes near the nasolabial fold with age. A future study with a more uniform population with distinct age groups would result in a stronger result to determine the correlation between age and volumetric changes in the soft tissues near the nasolabial fold.

The small sample size is another potential source of error in this research. The small subject number decreases the statistical power. The availability of patient of specific criteria along with having the images available inevitably resulted in a small sample size. As argued above, the number of patients could have been increased at the cost of increasing the variability in the population. The heterogeneity of the population however, would have resulted in a greater variability.

In our study sample, there were three different groups of ethnicities. The three different groups consisted of African Americans, Latinos, and Asians. Despite having similar skeletal classifications with either Steiner or Wits analysis, the different ethnicities could have contributed to the variability in the results. Different ethnicities have different facial morphology (Kim, JY., et al., 2016) and thus the changes in the soft tissues could contribute to varying results. During the statistical analysis, for example, regression analysis for Asians with the volumetric changes to the changes in lip thickness and lip position had the closest significance of 0.113. Future studies should also account for the morphological differences in between ethnic groups to determine the true effect of extraction treatment on nasolabial fold region.

The 3dMD images along with superimposition could have also introduced some errors. It is very difficult for anyone to activate the same muscles two seconds later, hence two years later post-treatment. Replicating the same neutral position is difficult and can lead to some variation. In addition, the soft tissues can fluctuate within hours due to diet, sleep, or physical activity. The dynamic state of the soft tissues makes it a difficult task to study, even when comparing changes in the same individual. Due to the dynamic state of the soft tissues, the most stable registration is completed in the shape of a "T" from the forehead to the nasal bridge as completed in previous studies (Croft, DL., 2009; Papasikos, J., 2013). To date, this is still the best method of superimposition and our intra class correlation was high indicating high repeatability. It is from this registration that the quantitative measurements were taken for the volumetric changes in the soft tissues surrounding the nasolabial fold. Unfortunately, all measurements are based on the registration of the forehead and not directly on the soft tissue surrounding the nasolabial fold areas.

Quantifying the nasolabial fold changes by measuring the volumetric changes that surround the nasolabial fold also had inaccuracies due to the variability in the "shape" of nasolabial fold amongst individuals. The deepening of the nasolabial fold is due to the soft tissue changes surrounding the nasolabial fold, and thus, the soft tissue volumetric changes would indicate a change in the nasolabial fold. Although the triangles drawn medial and lateral to the nasolabial fold were reproducible, the accuracy of the triangle to measure the volumetric soft tissue changes remains debatable. The triangles drawn may not have precisely delineated the soft tissue fold of the nasolabial fold which would have the greatest change. Indeed, due to the variable morphology of the nasolabial fold in individuals, it is difficult to trace a reproducible measurement that will include the soft tissue directly adjacent to the nasolabial fold. With increasing technological advances, a more accurate analysis may be performed in the future taking into the different morphology of the nasolabial groove in patients.

The qualitative analysis demonstrated variability amongst individuals similarly to the quantitative analysis. The subjects with the greatest differences in volumetric measurements in the quantitative analysis did not show the most significant retrusion or protrusion in the perioral region in the qualitative analysis and vice versa. This is due to the overall soft tissue changes. The color histogram (Figure 7 to 20) represents overall changes in the soft tissues in reference to the forehead region and thus the changes depicted in the color histogram only shows relative change despite the actual changes. In such situations, a subject who exhibited a slight positive change in the perioral region, but a larger change in the mandible, their overall color histogram will depict a positive mandible change with a slight negative change in perioral region. Thus, caution must be taken when interpreting these two data in conjunction.

Despite the variability in the qualitative analysis, overall changes in the seven regions were similar. Subjects who had negative changes were more likely to have negative changes in the other seven regions rather than a positive change, and vice versa. Upper lip retraction was not seen in all subjects despite the extraction treatment as seen in other studies (Beattie, JR., et al., 1994; Bishara, SH., et al., 1995; Bowman, SJ., 1999; Bravo, LA., et al. 1997; Hagler, BL., et al., 1998; James, RD., 1998; Johnson, et al., 1995; Leonardi, R., et al., 2010; Scott, SH., et al., 1999). In addition, the changes exhibited by the upper and lower lips did not translate to the same changes in the soft tissues medial and lateral to the nasolabial fold. Even with the relative proximity to each other, the soft tissue surrounding the nasolabial fold does not seem to be affected by the changes in the perioral region. This was in contrast with Papasikos findings who found the changes in the lower lip, nasolabial fold, and mentolabial fold were more dependent on treatment type (Papasikos, J., 2013). Further studies must be completed as our study lacked control subjects with non-extraction treatment. In contrast to the previous studies where the lower lip behaved more closely with extraction therapy (Franklin, BA., 2009; Ismail, SFH., et al., 2002; Moss, JP., et al., 2003), in our study, the upper and lower lip did not show significant histological differences in either retraction or protraction with extraction treatment in comparison to the upper lip.

The variations of our qualitative findings of the soft tissue changes that surround the nasolabial fold was congruent with Papasiko's finding: that the cheeks showed a variation in positive and negative changes regardless of treatment (extraction vs. non-extraction) and facial type (high angle vs. low angle) (Papasikos, J., 2013). This is in contrast to Uffner's findings of fuller cheeks in orthodontic treatment in high angle subjects with extractions. The low angle subjects with extraction, low angle with non-extraction, and high angle with non-extraction treatment had none or minimal changes in the cheeks (Uffner, N., 2013). In our study, mandibular planes were not taken into consideration.

The design of this study cannot answer the question if there is a greater difference in soft tissues near the nasolabial fold between thin and thick soft tissue patients in four premolar extraction orthodontic treatment. Some potential ideas for future research would be to increase the number of homogeneous population and use a more developed software program that will allow accurate assessment of changes in the nasolabial fold to produce a stronger result.

CHAPTER 7

CONCLUSIONS

1. Four premolar extraction treatments did not result in any significant changes with the soft tissue medial and lateral to the nasolabial fold.
2. There was no correlation between the volumetric changes in the soft tissue medial and lateral to the nasolabial fold in thick and thin soft tissue subjects.
3. There was no correlation between the volumetric changes in the soft tissue medial and lateral nasolabial fold to the lip protraction or retraction and upper incisor proclination or retroclination.
4. There was no correlation in the volumetric changes in the soft tissue medial and lateral to the nasolabial fold to age, ethnicities, and sexes.
5. The changes exhibited by the upper and lower lips did not translate to the same changes in the soft tissues medial and lateral to the nasolabial fold.

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APPENDICES

APPENDIX A
PATIENT DEMOGRAPHIC

Subject	ANB (˚)	Wits	Extraction	Age/sex	Race/Eth
1	4.3	3	U/L 4’s	12 F	Indian
2	0.2	-0.5	U/L 4’s	20 M	African American
3	1.9	-2.7	U4/L4,5	20 F	Hispanic
4	6	0.4	U/L 4’s	18 F	African American
5	4.6	-1	U/L 4’s	15 M	Hispanic
6	4.4	-4.4	U/L 4’s	15 M	African American
7	2.3	-5.2	U/L 4’s	12 F	Hispanic
8	3.7	-1.2	U/L 4’s	26 F	Asian
9	6.1	-1	U/L 4’s	21 F	Asian
10	4.5	0.6	U/L 4’s	21 F	African American
11	7.7	-1	U/L 4’s	17 M	African American
12	3.3	-5.6	U/L 4’s	12 F	Hispanic
13	6.5	0.2	U/L 4’s	13 F	African American
14	2.2	-1.7	U/L 4’s	15 F	African American

APPENDIX B
VOLUMETRIC CHANGES OF SOFT TISSUE MEDIAL AND LATERAL TO NASOLABIAL FOLD

Subject 1	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	1.624	1.739	1.492	1.58
	1.641	1.553	1.604	1.661
	1.568	1.553	1.604	1.661
Superimposition #2	1.575	1.612	1.602	1.560
	1.583	1.693	1.575	1.456
	1.475	1.645	1.570	1.550
Superimposition #3	1.621	1.706	1.649	1.577
	1.521	1.503	1.566	1.684
	1.611	1.636	1.684	1.706

Subject 2	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-23.912	-23.602	-23.877	-23.716
	-23.762	-23.836	-23.723	-23.738
	-23.902	-23.990	-23.723	-23.738
Superimposition #2	-23.740	-23.783	-23.717	-23.743
	-23.805	-23.813	-23.779	-23.692
	-23.860	-23.564	-23.881	-23.734
Superimposition #3	-23.646	-23.859	-23.931	-23.832
	-23.917	-23.581	-24.011	-23.715
	-23.741	-23.764	-23.616	-23.699

Subject 3	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-7.925	-7.940	-7.873	-7.907
	-7.783	-7.929	-7.812	-8.189
	-7.957	-7.787	-7.923	-8.073
Superimposition #2	-7.823	-7.771	-7.683	-8.376
	-7.884	-7.838	-7.688	-7.974
	-7.826	-7.666	-7.749	-8.041
Superimposition #3	-7.918	-7.843	-7.925	-8.066
	-7.84	-7.975	-7.709	-7.969
	-7.850	-7.923	-7.726	-7.906

Subject 4	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-1.566	-1.349	-1.649	-1.339
	-1.415	-1.233	-1.588	-1.430
	-1.536	-1.518	-1.310	-1.454
Superimposition #2	-1.010	-0.831	-0.958	-1.217
	-1.034	-0.762	-1.129	-1.281
	-0.947	-0.812	-0.999	-1.233
Superimposition #3	-1.117	-1.332	-1.127	-1.264
	-1.154	-1.187	-1.245	-1.217
	-1.126	-1.149	-1.347	-1.301

Subject 5	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	1.096	1.521	1.641	0.984
	1.183	1.234	1.625	0.697
	1.342	1.415	1.593	0.948
Superimposition #2	1.345	.1373	1.280	0.645
	1.416	1.250	1.247	0.828
	1.474	1.376	1.441	1.207
Superimposition #3	1.514	1.459	1.215	0.335
	1.440	1.343	1.221	0.599
	1.423	1.210	1.285	0.621

Subject 6	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-85.986	-86.041	-85.968	-86.062
	-86.062	-86.020	-86.276	-85.764
	-85.859	-85.105	-85.95	-85.901
Superimposition #2	-85.590	-86.633	-86.661	-86.400
	-86.440	-86.242	-86.553	-86.463
	-86.358	-86.468	-86.540	-86.345
Superimposition #3	-86.028	-86.269	-85.947	-85.920
	-86.127	-86.375	-85.978	-23.715
	-86.060	-86.262	-86.380	-85.924

Subject 7	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	69.074	69.158	69.172	69.098
	68.976	69.084	69.111	69.324
	69.045	69.290	69.129	69.300
Superimposition #2	69.288	69.388	69.243	69.366
	69.173	69.314	69.352	69.359
	69.149	69.354	69.308	69.330
Superimposition #3	69.388	69.387	69.466	69.635
	69.326	69.403	69.508	69.655

	69.314	69.354	69.530	69.426

Subject 8	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	91.260	91.695	91.541	91.211
	91.394	91.587	91.624	91.315
	91.395	91.555	91.809	91.429
Superimposition #2	90.626	90.794	90.841	90.613
	90.498	90.771	90.702	90.466
	90.529	90.705	90.585	90.564
Superimposition #3	90.479	90.680	90.723	90.423
	90.474	90.684	90.850	90.416
	90.477	90.668	90.798	90.526

Subject 9	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	247.270	247.130	247.280	247.250
	247.240	247.160	247.250	247.240
	247.220	247.180	247.080	247.270
Superimposition #2	246.376	246.274	246.227	246.381
	246.336	246.381	246.270	246.472
	246.333	246.257	246.277	246.362
Superimposition #3	246.128	245.957	246.139	-23.832
	246.043	246.029	246.018	246.118
	245.995	245.951	245.946	245.996

Subject 10	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	37.002	36.917	37.079	37.003
	36.914	36.917	36.932	36.924
	37.021	37.113	37.042	36.936
Superimposition #2	36.849	36.929	36.587	36.961
	36.887	36.955	36.782	36.869
	36.638	36.897	36.812	36.883
Superimposition #3	36.739	36.787	36.741	36.783
	36.851	36.667	36.554	36.890
	36.759	36.859	36.524	36.736

Subject 11	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	0.133	-0.093	-0.015	-0.021
	0.190	-0.122	-0.070	-0.040
	0.079	-0.330	-0.105	-0.037
Superimposition #2	-.128	-0.070	-0.036	-0.020
	0.096	-0.099	-0.038	-0.137
	-.107	-0.117	-0.111	-0.046
Superimposition #3	0.057	-0.084	-0.237	-0.033
	0.136	-0.140	-0.224	-0.066
	0.163	-0.085	-0.166	-0.025

Subject 12	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-0.028	-0.185	-0.173	0.004
	-0.064	-0.039	-0.010	0.152
	-0.014	-0.085	-0.057	0.045
Superimposition #2	0.012	0.023	-0.074	0.050
	0.013	0.027	-0.031	0.063
	0.007	0.022	-0.069	0.045
Superimposition #3	0.109	0.059	-0.072	0.050
	0.104	0.022	-0.009	0.096
	0.096	0.027	-0.095	0.040

Subject 13	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	-0.015	-0.018	-0.037	0.112
	-0.015	-0.027	-.014	-0.125
	-0.321	-0.137	-0.063	-0.170
Superimposition #2	-0.010	-0.038	-0.049	-0.114
	-0.023	-0.028	-0.052	-0.074
	-0.020	-0.015	-0.061	-0.073
Superimposition #3	-0.010	-0.038	-0.049	-0.023
	-0.023	-0.028	-0.052	-0.074
	-0.020	-0.015	-0.061	-0.073

Subject 14	Left_lateral	Left_medial	Right_medial	Right_lateral
Superimposition #1	3.446	3.555	3.594	3.581
	3.452	3.432	3.631	3.390
	3.454	3.656	3.625	3.232
Superimposition #2	3.293	3.438	3.507	3.490
	3.487	3.433	3.376	3.455
	3.464	3.332	3.517	3.466
Superimposition #3	3.421	3.326	3.524	3.379
	3.455	3.417	3.523	3.456

	3.596	3.539	3.575	3.506

APPENDIX C

CEPHALOMETRIC MEASUREMENT OF UPPER LIP PRE- AND POST- TREATMENT

Subject	UL-U1 pre-tx	UL-U1 post tx	U-lip to E-plane, Pre-	U-lip to E-plane, Post
1	11.5	11	-0.5	-3.9
	11.1	11	0.2	-3.9
	11	11.3	-0.8	-3.7
2	11.5	8.1	-1.2	-3.5
	11.3	8.5	-0.7	-3.1
	10.9	8.1	-1.1	-3.7
3	9.9	12.5	2.7	2.2
	9.4	12.5	2.8	1.9
	10	12.2	3.1	2
4	11.9	12.1	2.5	-0.6
	11.6	12	2.7	-0.9
	12.3	12.5	2.4	-0.5
5	13.5	13.9	5.8	0.3
	13.9	13.1	5.3	-0.2
	13.8	13.1	4.9	0
6	15	17.5	0.5	-1.1
	16.2	17.9	0.7	-0.8
	16	17.8	0.7	-0.6
7	9.8	12.9	-2.4	-2.4
	10.5	13.5	-2.3	-2.7

	10.6	13.6	-2.5	-2.6
8	10.5	11.5	0.4	-1.5
	10.5	12.3	0.7	-1.7
	10.4	12.1	0.2	-2.1
9	11.3	14.2	3.8	2.6
	11.6	14.9	3.0	2.4
	11.9	14.4	3.4	2.1
10	10.6	13.2	1.4	0.3
	11.2	13.2	1.2	0.1
	11.2	13.2	1.4	0.4
11	12.9	18.4	8.3	7.5
	12.9	18.4	8.3	6.9
	12.5	18.6	7.9	6.7
12	10.0	13.3	-1.2	-3.3
	10.6	13.8	-1.3	-3.5
	10.2	13.9	-1.5	-3.7
13	10.4	10.3	4.7	0.5
	10.9	10.5	5.0	0.4
	10.6	10.7	4.4	0.7
14	13.6	14.5	2.0	-0.1
	13.6	14.6	1.8	-0.7
	13.8	14.6	1.7	-0.5

APPENDIX D

CEPHALOMETRIC MEASUREMENT OF SN-U1
PRE- AND POST TREATMENT

Subject	SN-U1 pre-tx	SN-U1 post-tx
1	119.1	99.5
	120.0	99.7
	120.0	99.8
2	145.0	111.2
	145.9	110.1
	145.6	111.4
3	116.8	104.9
	116.4	106.0
	116.0	106.2
4	114.6	92.7
	115.1	92.1
	114.1	93.9
5	122.9	101.2
	122.5	101.1
	122.7	101.3
6	101.0	102.5
	101.3	102.0
	101.3	102.1
7	102.8	103.5
	102.4	102.9
	102.6	102.6
8	119.7	105.2
	120.0	105.1
	119.7	104.7
9	99.5	101.1
	99.5	100.7
	99.8	100.9
10	117.1	116.0
	117.0	116.5
	117.5	116.4
11	117.5	98.9
	117.4	98.5
	117.6	98.4
12	120.0	112.8

	120.5	112.5
	120.1	112.8
13	115.5	102.5
	115.3	102.7
	114.8	102.6
14	123.9	118.4
	123.8	118.2
	123.4	118.6