THREE-DIMENSIONAL ASSESSMENT OF THE EFFECTS OF EXTRACTION ON THE SMILE IN CLASS II HIGH AND LOW MANDIBULAR PLANE ANGLE PATIENTS

A Thesis

Submitted to

The Temple University Graduate Board

In Partial Fulfillment

Of the Requirements for the Degree

MASTER OF SCIENCE

By

Neil E. Uffner, DMD

August 2013

Thesis Approvals:

Orhan C. Tuncay, DMD
Thesis Advisor, Orthodontics

Jeffrey H. Godel, DDS
Committee Member, Orthodontics

Dr. Jie Yang, DMD
Committee Member, Radiology

ABSTRACT

The annals of orthodontics are filled with studies aimed to understand how extraction orthodontic treatment might change the face. Although many studies have addressed profile changes due to extraction treatment, fewer studies have focused on how extractions change a patients smile. With the advent of surface imaging systems such as 3dMD, it is now possible to visualize the smile, and any changes incurred during orthodontic treatment, in three dimensions.

Subjects for this study were chosen from the pool of 11-18 year old patients treated at the Podray Orthodontic Clinic at the Temple University Kornberg School of Dentistry. Subjects were Cl II patients, and must have been treated with either extraction of any combination of premolars or treated without extraction. Subjects were divided into four experimental groups based on two characteristics- mandibular angle (those with angles greater than 28^{o} versus those with angles less than 28^{o}) and treatment (extraction versus non-extraction). The resulting groups were separated as follows: high-angle extraction patients (n=8), low-angle extraction patients (n=6), high-angle non-extraction patients (n=7), and low-angle non-extraction patients (n=15).

For each subject initial and final 3dMD images were superimposed using 3dMD Vultus software. A color histogram was constructed to visualize changes during treatment. The cheeks, commissures, upper and lower lips, chin, and nose, were also landmarked, and the changes in these landmarks were calculated. Volume changes were also calculated between pre and post treatment 3D data.

Results showed that the lower lip and right commissure changes between high-angle extraction and non-extraction groups were statistically significant. A qualitative analysis of the histograms further supported these findings. In general, a greater change in soft tissue landmarks and soft tissue volumes could be seen in high-angle patients than low-angle patients.

Differences in the changes that result from treatment type (extraction vs. non-extraction) were seen in the high-angle group. In contrast, similar changes result from treatment type (extraction vs. non-extraction) in the low-angle groups. Furthermore, the lip changes seen in extraction patients upon smiling are very similar to those changes seen in the same patient in repose. Most interestingly, soft tissue differences of the face due to treatment, growth, or both, seem to disappear upon smiling, with the exception of the lips. Qualitative assessment of these changes in the smile might be a more appropriate method for identifying soft tissue changes than statistical analyses. Similar studies with larger sample sizes are a promising direction for future research.

ACKNOWLEDGEMENTS

I would like to thank the special people who made this project possible:

- Dr. Tuncay, for your expertise in three-dimensional imaging, and your continual guidance and mentorship throughout the course of this project. Your dedication to Temple Orthodontics has propelled this program to the forefront of orthodontic education. I'm grateful you have given me the chance to be part of this program and this specialty.
- Dr. Godel and Dr. Yang, for taking time from your busy schedules to attend our committee meetings and serving as constant sources of motivation and knowledge. Dr. Godel, your commitment to the department can't be ignored. I have no doubt you will continue to lead Temple Orthodontics to unchartered territory.
- Dr. Hardigan, for your masterful statistician work
- Hasmi Patel, for all your meticulous hard work at the 3dMD computer
- The part time faculty at Temple University Department of Orthodontics, who have made my clinical experiences here second to none. I hope you all will continue to be large parts of both my professional and personal life.
- The rest of the Class of 2013 and the Class of 2014 for their patience and support in gathering smiling and non-smiling 3D data.
- My incredible parents, Jeff and Amy Uffner, who have truly provided giant sized shoulders for me to stand on and see the world, my brother Stu, and Jackie, for bearing with me during many long nights, and all their unconditional love.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Edward Angle, the father of modern orthodontics, had strong beliefs that a full complement of 32 adult teeth was necessary for an ideal occlusion. This Angle non-extraction philosophy was the orthodontic dogma in the early years of the specialty. In the early 20th century, Calvin Case was the first orthodontist to publicly challenge non-extraction as the standard of care, arguing that facial esthetics were often compromised when maintaining all 32 teeth. Case's dissention marked the beginning of a passionate, verbose, and sometimes personal, extraction verse non-extraction debate that remains in the focal point of the orthodontic profession today (Proffit, 2007).

Since the days of Case and Angle, the popularity of orthodontic extraction treatment has followed distinct trends. During the 1950's and 1960's extraction gained its highest popularity under the influence of two of Angle's students, Charles Tweed and Raymond Begg. By the mid 1960's nearly half of patients undergoing orthodontic treatment had extractions. This popularity has since reversed. Both growing beliefs that extractions do not guarantee post-treatment stability and an increased sensitivity to culturally dependent standards for facial esthetics have led to a recent decline in orthodontic extractions (Proffit, 2007).

The study of facial esthetics is well established. Changes in the profile have been identified and quantified; however, changes in the smile due to extraction treatment are much less documented. Furthermore, all studies focusing on the smile, until now, have been conducted with a 2 dimensional methodology. In 1995, Johnson and Smith did not find a predictable relationship between extraction of premolars and the esthetics of the smile. In their study, the only variable that strongly predicted success of treatment was which orthodontist the patient visited. In 2003, Kim and Gianelly compared smiling photos of patients treated with or without premolar extractions. They also concluded that the aesthetic outcome was independent of extractions.

The use of the 3dMD system, a relatively new technology, allows the orthodontist to quantify soft tissue smile changes. The 3dMD system is a popular 3 dimensional (3D) stereophotogrammetric machine. 3D stereophotogrammetry is a technique that can be used to capture 3D surface images. The 3dMD system employs six cameras, three on each side. One camera on each side is a color camera and the other two are infrared cameras. In addition to a 3D surface model, the 3dMD system also captures photo-realistic images. Once the 3D surface rendering is completed, photo-realistic images are morphed to this rendering, and the result is a life-like representation of the subject. Incrapera et al. have verified the accuracy of superimposing 3D stereophotographic images, and concluded that superimposition techniques used in different imaging modalities (2 dimensional versus 3 dimensional) are comparable with one another (2010).

As previously stated, little has been published on the 3D effects of extraction treatment on the smile. In particular, the ways the cheeks, lips, and commissures behave in a smiling patient who received orthodontic treatment are unknown. Characterization of the changes orthodontists make to these structures could improve our diagnostic abilities. An understanding of these effects would improve pretreatment esthetic predictions and help guide the treatment planning process.

CHAPTER 2

LITERATURE REVIEW

2.1 Significance of the Smile

Some would say a smile is the most immediate and expressive gesture the human body is capable of creating, and a signal for our emotions. Smiling can convey feelings of happiness, excitation, and desire. It can be a sign of greeting and acceptance, attraction, deceit, or awkwardness.

The gold standard of evaluating orthodontic treatment outcome has long been achieving ideal occlusion. The last half-century has seen this emphasis shift drastically. Paternalism in medicine and dentistry has been replaced with symbiotic doctor-patient relationships. Following this trend, orthodontics has seen the emergence of a soft tissue paradigm, which highlights the importance of a patients' appearance among a plethora of dental and skeletal diagnostic markers. A patient's own long term satisfaction with his or her smile has become the ultimate determinant of successful orthodontic treatment.

2.1.1 History of Human Esthetics and the Smile

A human appreciation for anatomic form dates back to Paleolithic time and would likely have manifested earlier if the harsh conditions of the Stone Age had not limited prehistoric man's time for leisure (Peck and Peck, 1970). Animal murals found in the Lascaux Caves in southern France represent the earliest record of human acknowledgement of the anatomic form.

Although these prehistoric communities had an awareness of physical form, it was not until the Egyptian Civilization, nearly 30,000 years later, that human facial anatomy was depicted with realistic proportions rather than anatomical distortion. The Egyptians developed the first consistent artistic style. In sculpture, the Egyptian "ideal" consisted of a round, broad face with a sloped forehead, weak brow ridge, prominent eyes, evenly contoured nose, thickened lips and mild yet positive chin. Interestingly, modern day orthodontist might see Egyptian sculptures as bimaxillary protrusive (Peck and Peck, 1970).

Building on the Egyptian establishments of artistic realism, Greek artists were the first to develop a concept of facial esthetics and beauty. The Greeks placed particular emphasis on anatomic harmony (1970). Beauty was dependent on natural harmony and respect of certain geometric principles. According to Plato, true beauty was only achieved with, "due observance of proportions (1970)."

Greek reproduction of the human smile began in the Archaic period (650-480 B.C.), which marks when Greek sculptors first carved in stone. Works consisted mainly of young nude men, young clothed women, and sphinxes, many of which appear to be feigning a smile. Termed the "Archaic Smile" by contemporary art critics, this smile is flat and unnatural looking. The purpose of these expressions might have been to depict that the subject was alive and infused with a sense of well-being (Trumble, 2004).

The Classical Era (500BC-335 BC) of Greek sculpture followed the Archaic period, and coincided with the Greek transition from an aristocratic state to a democratic state. Edward Angle, who was introduced to Greek sculpture by art professor E. H.

Wuerpel during the beginning of the 20th century, was profoundly influenced by this Classical movement. Angle drew much of his aesthetic muse from Greek masterpieces such as the Venus de Milo and the Apollo Belvedere. He had said of the face of the Apollo Belvedere that, "Every feature is in balance with every other feature and all the lines are incompatible with mutilation of malocclusion." It must be noted that neither of these works depict the subject smiling.

The Classical Era denotes the peak of the Greek aesthetic. The Hellenistic period of Greek sculpture began under the rule of Alexander the Great (336 B.C.). The Hellenistic period saw a departure from the idealistic beauty seen in past eras to a more realistic rendering of subjects.

Hellenism continued to dominate the European world until the fourth century A.D. At this time, Europe entered the Dark Ages. Growing religious movements in Europe began to condemn physical beauty and aesthetics in favor of spiritual beauty. Principles of morality, rather than natural proportions, began to govern facial esthetics. In painting, artists depicted subjects to have extremely small mouths proportional to the rest of the face. When mouths were painted opened, teeth were crooked. The artistic smile was lost, and most subjects were painted void of all facial expression (Trumble, 2004).

Beauty, proportionality, and realistic esthetics, last seen during the Classical Greek period 2,000 years before, were reintroduced during the renaissance. Leonardo da Vinci's *Mona Lisa,* which he painted between 1503 and 1506, marks one of the first paintings to successfully display a smile. Lacking a distinct outline of the corners of her mouth and the corners of her eyes, Mona Lisa's smile appears both intensely realistic, and eerily subtle. Like the *Mona Lisa,* Frans Hals' *Laughing Cavalier,* painted in 1624, depicts a male with a similar closed mouth smile. Self-portraits of Jean-Etienne Liotard and Johann Aaachen are two rare examples of Renaissance paintings featuring full smiles (Trumble, 2004).

Depicting smile in art became a risqué venture during the British Victorian Era from the late 18th to the late 19th centuries. Due to poor dental care, unaesthetic dentions were the norm. Most subjects were painted with mouths closed. A wide-mouth depiction of horrible teeth was often used as a metaphor for obscenity, greed, or other corruption. English satirists James Gillray and George Cruickshank often featured the antagonists in their works with full smiles. Similarly, artists of this time also began experimenting with the smile to push moral limits. Ford Madox Brown and William Holman Hunt were leaders of this movement. In Hunt's *The Awakening Conscience,* and Brown's *Work,* open-mouthed smiles are associated with desire, lust, adultery, and deviance (Trumble, 2004).

In contemporary times, the smile has lost much of its symbolic significance. Photography has become the favorite form of mass media. As we progress through an age of individuality, smart phone cameras, and social media outlets, the human smile has never before been so ubiquitous.

The smile's place in art can be dated back to pre-historic times. The smile has only more recently been the focus of scientific exploration. Facial expressions and the smile first became scientifically relevant after Darwin published *The Origin of Species* in

1859. Thirteen years later, Darwin published the lesser-known *The Expression of the Emotions in Man and Animals*, in which he used the similarities in facial expression among different species as evidence of shared evolutionary ancestors.

In the 1860's and 1870's, Guillaume Duchenne showed that there are different muscles in the human face that are separately responsible for each individual emotion (Snyder et al., 2010). Duchenne was also the first to define the smile in physiological terms. The "Duchenne smile," is produced via contraction of the zygomatic major and orbicularis oris. Although other muscles can simulate a smile, Duchenne believed that only these two muscles acting in tango can produce a genuine expression of positive emotion. While the adaptive functions of facial expression continue to remain largely unknown, the smile as a universal tool for communication cannot be debated (Schmidt and Cohn, 2001; Parr and Waller, 2006).

2.1.2 Social Importance of the Smile

There is extensive literature regarding the value of an attractive smile in modern society. A smile often influences initial reactions and attitudes from others. A person is more likely to attribute positive traits such as reliability and high qualification to those individuals who are perceived as more attractive than those that are perceived as less attractive (Christenson, 1981). These more attractive folks are also more likely to receive better treatment. According to Walster, in some social situations, physically attractive people may be at an advantage (1966). These attraction biases are first evident when children are very young. It has been reported that teachers systematically rate attractive children more favorable than less attractive children. In addition, teachers are more likely to hold lower expectations and see the need for special education for less attractive children (Ross, 1975). Preferential treatment of attractive students continues into high school and early adulthood. Shaw found that perceptions of friendliness, high school standing, popularity, and intelligence all accompany social attractiveness (Shaw, 1985). More recently, Sinko et al. asked raters to evaluate the initial and final photographs of 8 skeletal Class II patients and 8 skeletal Class III patients treated with surgery. Raters were asked to evaluate both aesthetics and perceived personality traits from the sets of photographs. Both Class II and Class III patients showed an improvement in aesthetics after the surgery. Both groups also showed an increase in perceived intelligence, again suggesting an unconscious process in the human estimation of others personality traits (2010). Along similar lines, high school students with ideal smile esthetics were perceived to be more athletic, more social, and have better leadership qualities, than other students with non-ideal smile esthetics (Henson et al., 2010; Perkins et al., 1995).

Studies that focus on the effects of physical appearance on one's own attitude further the argument of an attraction bias. An individuals' attitudes, and in turn his or her actions, are closely linked to his or her self-concept. If an individual is called "beautiful," and this becomes part of his or her self-concept, future behavior is more likely to follow. As a result, an individual with a self-concept of beauty is more likely to be socially desirable, happier, and more successful individual than a counterpart (Dion, 1972). Attractive people are preferred as potential friends, and the degree of attractiveness can influence the way an onlooker might evaluate his or her performance (Landy, 1974).

On the other hand, the effects of poor dental esthetics can also stereotype a person as lacking self-confidence (Jenny et al., 1990). Jenny and Proshek demonstrated that malposed teeth and malocclusions could deleteriously affect employment. Esthetic smiles were found to be most important for political and professional careers (Jenny, 1986.) Through systematic review, Liu, McGrath, and Hagg concluded that malocclusion does have a small impact on an individuals' quality of life (2009).

Parents, who most often deal with the financial burden of orthodontics, appear to understand this trend. The most important motivation for treatment is improvement of facial esthetics because of the belief that increased social and financial opportunities might result (Dorsey, 1977). Parents report greater motivation for orthodontic treatment than the children receiving treatment (Daniels and Seacat, 2009). According to Linn, eighty percent of the subjects in his survey felt that orthodontic care for their children was more worthwhile investment than buying a house (Linn, 1966). This trend can be expected to continue as the media emphasis on good looks continues to grow, and the self-esteem of many young adults is directly tied to appearance (Patzer, 1995).

Perception of physical attractiveness occurs effortlessly. Simple cues, often obtained on short glance, allow individuals to differentiate between levels of attractiveness (Locher, 1993). Further research shows that eyes and the mouth are the two features most commonly associated with facial attractiveness (Baldwin, 1980). Thus, the smile must be considered a crucial factor in one's social interaction and success.

2.1.3 Smile Esthetics

2.1.3.1 Display of teeth

An overview of the esthetics of a smile must begin with the maxillary anterior teeth. The maxillary anterior segment, from upper right canine to upper left canine, is the most visible portion of the smile. These six teeth are often referred to as the "social six." Although these are the most prominent teeth in a smile, they are not the only teeth visible on smiling. An attractive smile includes the maxillary anterior teeth in full view, but also includes display of the maxillary posterior segments up to the first molar (Dong, 1999).

Another frequently used esthetic evaluator is the lip line. The lip line refers to the margin where the upper lip ends and, when viewing a patient from the front, incisors can be seen. The lip line is ideal when the upper lip reaches the gingival margin and the entire length of the maxillary central incisors can be seen. This is the case in 70 percent of the population. A patient with a low smile line will display 75 percent or less of the maxillary central incisors, whereas a patient with a high smile line will display the entire length of the central incisor and a band of gingiva (Dong, 1999; Tjan, 1984). Female lip lines are on average 1.5 mm higher than males. A female displaying 2 mm of gingiva on smiling might be considered normal (Peck, 1992; Rigsbee, 1988).

2.1.3.2 Smile Arc

The smile arc describes the contour of the incisal edges of the maxillary anterior teeth in relation to the margin of the lower lip and is a valid tool to evaluate smile esthetics (Proffit, 2007; Passia et al., 2011). Maxillary incisal edges that follow the curvature of the lower lip allow for optimal esthetics. A smile with maxillary teeth in a straight line or a reverse arc with the lower lip is less esthetic (Parekh, 2007).

According to Ackerman and Ackerman, the smile arc is affected by two main factors: the sagittal cant of the occlusal plane and archform. A clockwise sagittal cant of the occlusal plane will increase consonance of the smile arc. Conversly, a broader arch form will result in a flatter smile arc (1998).

2.1.3.3 Upper Lip Curvature

The curvature of the upper lip can be classified based on the relationship between the center of the lip and the corners of the mouth. Three types of curvatures exist: upward, straight, or downward. Upward and straight curvatures are considered more esthetic (Dong, 1999). In orthodontic populations, 45 percent of patients have a straight curvature, 43 percent have a downward curvature, and 12 percent have an upward curvature (Dong, 1999).

2.1.3.4 Archform

The dental archform, particularly the transverse dimension of this archform, is also a defining characteristic of a smile. A broader smile is often more attractive, however, this is not always the case. A dimension of interest is the amount of buccal corridor that is shown on smiling. The buccal corridor is the dark space that exists between the maxillary posterior teeth (especially the premolars) and buccal mucosa of the cheek (Proffit, 2007). According to prosthodontic literature, completely eliminating the buccal corridor results in an unrealistic "denture smile" (Sarver, 2003). Observers prefer a buccal corridor that is in harmony with the smile and other facial features (Lombardi, 1973; Miller, 1989; Dong, 1999; Sarver, 2001). Recent research has shown that the amount of buccal corridor might not be as important as once thought. According to Kokich et al., there is a threshold level at which anything less than this amount of buccal corridor becomes visible and unattractive to lay people (1999).

2.1.3.5 Microesthetic Components

Microesthetic components of the smile include proportion, size, shape, color, and alignment of teeth, midline and symmetry of the dental arch, and gingival architecture. Ideal maxillary incisor height to width ratio is often described as 1:0.8. Others have reported this ratio to vary between 66 – 80 percent. (Sarver, 2004; Gillen, 1994). Mahshid noted that the golden proportion is not a requirement to have an attractive smile (2004). Gingival heights must also be proportional. Gingival connectors must be greatest in between the central incisors, and moves apically in a progression from the anterior to posterior teeth (Proffi,t 2007). Interestingly, midlines coincident with the face are not required for ideal esthetics; ideal esthetics are not compromised as long dental midlines are within 2 mm of the facial midline (Kokich, 1999).

2.1.3.6 Eyes

Muscles of facial expression responsible for a smile are not limited to the lips. Muscles surrounding the eyes also play a role in a pleasing smile. In a 2004 Temple masters thesis, Arturi qualitatively determined the role of the eyes in forming impressions on the smile. He measured extraoral muscle contraction, which he termed “eye squint.” He concluded that individuals who smile with a moderate level of eye squint have a significantly more favorable first impression than those individuals who smile with either minimal or high eye squint.

2.1.3.7 Soft Tissue considerations

The upper and lower lips that frame the smile are dynamic drapings. Ideally, the full length of the maxillary incisor is displayed on smiling, and the incisal edge curve follows the lower lip. At rest, 2 mm of the incisors are shown. Increasing the amount of incisor display gives a bolder and more youthful appearance (Miller, 1989).

With or without orthodontic treatment, the position of the upper and lower lips will change during the course of a lifetime. This can be due to natural flattening, stretching, and depleted skin tonicity experienced as a person grows older (Peck, 1992). As expected, this decreases maxillary anterior display and increases mandibular tooth display (Vig, 1978).

Patient ethnicity must also be considered when soft tissue is evaluated. The attractive African-American is characterized as slightly more convex and protrusive compared to other ethnic norms (Farrow et al., 1993; Hall et al., 2000). Applying cephalometric norms for one ethnicity to another is a diagnostic error.

2.2 The Great Debate: Extraction vs. Non-extraction

Extraction of permanent teeth for orthodontic treatment has long been a controversial issue. Throughout the 1800's extraction of premolars was often used to treat Class II Division I malocclusions. Calvin Case was an early proponent of extractions. In 1893, he argued that expanding the arches, rather than extracting teeth, produces inferior esthetics and stability.

Case's biggest opposition came from Edward Angle. Edward Angle was an early and dominating opponent of extractions. Angle, and his student Martin Dewey, believed that a functioning, and complete, occlusion would maintain teeth in there correct positions. In July 1911, at the National Dental Association's annual meeting, Calvin Case gave a lecture on, "the question of extraction in orthodontia." The ensuing discussion erupted into an outright verbal brawl. Dewey, who spoke on behalf of the non-extractionists, attacked Case's credibility and ridiculed him. Despite Case's impressive and sound arguments, Martin Dewey won the battle of words, and non-extraction treatment dominated for the next 30 years.

During the 1950's and 1960's extraction treatment again became popular under the influence of two of Angle's students, Charles Tweed and Raymond Begg. Claiming that extraction of 4 premolars improved facial harmony and improved stability, Tweed developed the Tweed triangle and a series of rigid, time-consuming, mechanics to successfully manage extraction spaces. Begg noted that Australian aborigines, who had excessive interproximal wear, did not have dental crowding. After two years of non-extraction treatment, he began extracting premolars (Wahl, 2005). By the mid 1960's nearly half of patients undergoing orthodontic treatment had extractions.

Recent years have seen a decline in extraction treatment for several reasons. First, research focusing on the stability of the dentition either with or without extractions has proved inconsistent (Proffit, 2007). Extraction does not necessarily guarantee a more stable post-treatment outcome. Second, most orthodontists now acknowledge that the standards for facial attractiveness are largely cultural dependent. These standards continuously change with time. The current general population prefers fuller, more protrusive lips than the orthodontic standards of the 1950s and 1960s. Borderline cases that may at one time have been treated with extractions are now often treated non-extraction in order to maintain lip positions.

Inconclusive empirical evidence, inconsistent treatment modalities, cultural changes in aesthetic preferences, and the nature of orthodontics as a specialty strongly infused with esthetic and diagnostic opinion, all contribute to the continuing resonance of the extraction debate.

2.2.2 Changes in the smile as a result of orthodontic extractions

The literature indicates that extraction treatment can result in esthetic finishes when properly diagnosed and executed. Essentially, orthodontist can change the face for better or for worse (Bisara et al., 1995; Boley et al., 1998; Bowman and Johnston, 2002; James, 1998). Numerous studies have discredited generalizations such as "extraction treatment dishes the face in" (Beattie et al., 1994; Boley et al., 1998; Bowman, 1999;

Drobocky and Smith, 1989; Paquette, 1992; Wholley and Woods, 2003). In fact, when viewing final treatment photos, orthodontists are unable to judge whether extraction or non-extraction treatment was rendered (Rushing, 1995).

Profile changes due to extraction or non-extraction treatment are becoming better understood. Most studies report 2 mm of profile retraction with four-premolar extraction (Bishara et al., 1995; Bishara and Jakobsen, 1997; Bowman and Johnston, 1992; Scott and Johnston, 1999). Drobocky and Smith also noted a change in the nasolabial and labiomental angles in Caucasian patients treated with four-premolar extraction. The nasolabial angle increased by 5.2^{o} and the labiomental angle increased by 2.7^{o} (1989). Using 3D stereophotogrammetry, Ismail et al. supported this finding. The British group used 3D technology to compare pre- and post- treatment records of 12 extraction patients and 12 non-extraction patients. In their limited patient population, concavity of the labiomental fold increased in the extraction group and was unaffected in the non-extraction group (Ismail et al., 2002).

Just as extraction treatment has the potential to change a profile, Bowman and Johnston showed that non-extraction treatment has very little to no effect on the profile. Bowman and Johnston established a guideline - they advocated that extraction treatment should be avoided in patients with lips 2-3 mm posterior to Rickett's E-line (2000). Many other studies support this same theme that extraction treatment creates greater facial change than non-extraction (Beattie et al., 1994; Bishara et al., 1995; Bishara and Jakosben, 1997; Bowman and Johnston, 2000; Bravo, 1994; Drobocky and Smith, 1989; James, 1998; Paquette, 1992; Scott and Johnston, 1999). In 1998, James compared the post-treatment profiles of 170 consecutively treated patients. Of these patients, 108 had extraction treatment, and 62 had non-extraction treatment. James concluded that every single patient finished within the esthetic range as defined by the Rickett's E-line and Merrifield Z angle. James not only concluded that both treatment modalities finish with esthetic results, but that those treated with extractions had the greatest esthetic improvement (1998). Scott and Johnson asked African American orthodontists, Caucasion orthodontists, and lay people to compare pre- and post-treatment profiles of extraction and non-extraction patients. All judging groups preferred the post-treatment extraction profiles. They concluded that patients treated with extraction had more severely protrusive initial profiles. As such, the improvements in these patients, as opposed to the non-extraction group, were more drastic (Scott and Johnston, 1999).

While changes in the profile have been identified and quantified, changes in the smile due to extraction treatment are much less documented. The current literature seems to come to an overwhelming consensus that extraction treatment itself plays little role in post-treatment smile esthetics. It must be noted that to date, only 2 dimensional data is available. Johnson and Smith asked 10 lay people to judge smiling esthetics of frontal smiling photos of 60 retention patients from 3 different offices. They concluded that there was no predictable relationship between extraction of premolars and the esthetics of the smile. In fact, the only variable that strongly predicted success of treatment was which orthodontist the patient visited (1995). Kim and Gianelly compared casts of 60 patients, half treated with extraction and half without, and smiling photos of 12 of the extraction patients and 12 of the non-extraction patients. Arch width was measured on the casts between canines, premolars and molars. Surprisingly, the extraction group had a wider arch in the molar region. All other width measurements were similar. They concluded that arch width was not decreased in extraction treatment, and the esthetic result was the same in both groups (2003). These transverse findings supported the work by Luppanapornlarp and Johnston (1993). In 2006, a Turkish group asked a panel consisting of parents and dental professionals to rate the smiles of 25 patients treated with extractions, 25 patients treated without extractions, and 25 untreated patients. They concluded that transverse characteristics of the smile had little significance on esthetics. Instead, maxillary gingival display and final position of the anterior teeth were major esthetic indicators. Agreeing with previous reports, treatment modality alone has no predictable effect on the overall esthetic assessment (Isiksla et al., 2006). Ghafar and Fida repeated a study of similar design, and again concluded that extraction and non-extraction treatment produce comparable esthetic results (2012).

2.3 3D Soft Tissue Imaging

2.3.1 2D Imaging Limitations

The photograph and the cephalogram are the mainstays of two dimensional imaging and much of the substance of orthodontic records. Our discussion of two dimensional imaging limitations will focus on these techniques.

The first limitation, and perhaps most significant, is the fact that a photograph or cephalogram is a two dimensional representation of a three dimensional object. Imaging a three dimensional form in only two dimensions will inherently produce distortions.

When using photography, objects that are closer to the camera lens will always appear larger than those that are farther from the camera lens. Several authors have acknowledged that this error might skew photographic evidence (Bishara et al., 1995; Bishara and Jakobsen, 1997; Gavan et al., 1952). This limitation in cephalometrics causes anatomical structures to be displaced both vertically and horizontally in proportion to the distance they are from the film (Quintero et al., 1999).

Another limitation of photogrammetry and cephalometery is the difficulty of identifying reproducible landmarks. In 1994, Farkas, a physical anthropologist, compared photographic analysis to direct anthropologic analyses. His results showed that 40 percent of the anthropologic points could not be identified from the photos alone. Of the remaining 60 percent, only one third of these points had acceptable concordance with direct measurements (Farkas, 1994). Bishara et al. echoed this uncertainty of photogrammetric landmarks. Because landmark placement on photographs was not reliable, linear measurements between two points were incorrect. In addition, the problem was exasperated if angular measurements, which require three correct landmarks, were to be used. Landmark identification is also a major source of error in cephalometrics. Lack of well-defined anatomical borders and radiographic shadows can significantly decrease consistency in identifying common radiographic landmarks (Athanasiou, 1997).

Patient positioning proves to be another issue when using cephalometery, however, is of greater concern when using photography. Unlike the earpieces found in a cephalostat, there is no guide to help the patient maintain natural head position. This allows free motion, and a patient can tilt their head up or down. This rotation around the x-axis can cause severe vertical distortion. The patient's head will appear elongated when it is tipped up or shortened when tipped downward (Bishara et al., 1995). The use of stabilizing devices mitigates this problem, but severely impairs visibility of landmarks, particularly those around the ears (Cummins et al., 1995).

A review of the limitations of photogrammetry would not be complete without acknowledging the debate over the reproducibility of certain facial expressions. Unlike other limitations, this concern is unique to photogrammetry. The influence of facial expressions on position of landmarks is particularly important when evaluating multiple photographs of the same patient at different times. In 2002, Ackerman and Ackerman demonstrated that if multiple photographs are taken during the same orthodontic visit, a patient might display multiple variations in their smile (2002). Similarly, Sarver suggests that a social smile can mature over time in some patients (Sarver et al., 2002).

On the other hand, multiple studies have shown that very little differences are seen between photographs at different time points or between social and posed smiles (Hulsey, 1970; Rigsbee, 1988). Sawyer et al. used 3D stereophotogrammetry to assess the reproducibility of facial expressions over a four week period. Unsurprisingly, the group found the "repose" expression to be the most reproducible. The "smile with lips open" expression showed a variability of .21mm. The authors concluded that although a "smile with lips open" expression showed less reproducibility, differences over four weeks were minimal, and this was not clinically significant (1999). Furthermore, after observing both treated and non-treated patients for 2.5 years, Ackerman found little differences in the characteristics of the social smile (1998). The fields of orthodontics, psychology, sociology, neurobiology, and physiology, continue to debate this heated topic.

2.3.2 3D Stereophotogrammetry

Amidst the growing emphasis on soft tissue and 3D technology, 3D stereophotogrammetry has seen an increase in popularity in the medical field, particularly among plastic surgeons, oral surgeons, and orthodontists. Stereophotogrammetry is a technique defined as “combining multiple views from photographs to form a 3D image” (Kau et al., 2007). The technology mimics human binocular vision, in which the right and left eyes produce slightly different images which are then reconstructed to create a perception of depth (Halazonetis, 2001). 3D stereophotogrammetry relies on structured light to transmit surface texture. As structured light illuminates the subjects’ surface, this light pattern bends and distorts. A system of cameras at known distances and angulations from the subject captures the reflected light. A computer processes this light and its angulation, and a 3 dimensional surface is created (Kau et al., 2007).

Multiple companies sell 3D stereophotogrammetry imaging devices, and each comes with its own software. This software includes tools for superimpositions of multiple images, landmark tracing, and volume and surface area calculations.

2.3.2.1 Accuracy of acquisition and superimposition

The accuracy and precision of 3D stereophotogrammetry as a tool for quantitative research has been confirmed in the literature. In 2006, Weinberg and associates investigated the accuracy and precision of identifying landmarks from the Genex system, 3dMD system, and direct anthropometry. The group paid particular attention to intra-observer consistencies. To control for difficulties in patient positioning, all measurements were taken on an inanimate manikin head. They found no significant differences in measurements between the three groups. Furthermore, intra-operator imprecision was at the submillimeter level. Studies by Heike et al. (2009) and Wong et al. (2008) also attest to the accuracy of 3D stereophotogrammetry.

Similarly, Lubbers and team focused on the accuracy of the 3dMD system. To minimize errors from subjective landmark identification, the team labeled 41 landmarks on a manikin, and then captured this manikin with a 3dMD machine. Subjects measured the distance between landmarks using either calipers or the computer software five separate times. The team found that the accuracy of the 3dMD system was more than sufficient. In fact, measurements made using 3dMD software were more accurate and more precise than other methods, including direct anthropometry and two-dimensional photography.

The accuracy of superimposing 3D stereophotographic images has also been explored. Incrapera et al. aimed to evaluate the superimposition techniques of cephalometrics and 3D stereophotogrammetry, and compare the accuracy of the two. Pre- and post-treatment lateral cephalograms of 40 orthognathic surgery patients were superimposed on SN and the anterior cranial base. 3dMD images of these same 34 patients were superimposed using a regional fit environment, which incorporate the broadest area of the forehead, soft tissue nasion, and the bridge of the nose. Five common soft tissue landmarks were identified on pre-and post-treatment records. Measurements between pre- and post-treatment records were then recorded. The researchers found no significant differences in linear measurements between 2D and 3D superimpositions. It was concluded that superimposition techniques used in different imaging modalities are comparable with one another (2010).

2.3.2.2 3dMD System

The Temple University Orthodontic Clinic currently uses the 3dMDface System, made by 3dMD in Atlanta, Georgia. This system employs six cameras, three on each side. One camera on each side is a color camera and the other two are infrared cameras. In addition to a 3 dimensional surface model, the 3dMD system also captures photo-realistic images. Once the 3 dimensional surface rendering is completed, photo-realistic images are morphed to this rendering, and the result is a life-like representation of the subject.

The 3dMD system has several advantages over other imaging and 3D stereophotographic machines. The 3dMD system uses neither laser technology nor radiation, and thus provides a safe means of image acquisition. Futhermore, the 3dMD has an extremely fast capture time of 2 milliseconds. Short capture time allows for easy patient compliance, and thus minimal error due to patient positioning (Halazonetis, 2001).

CHAPTER 3

AIMS OF THE INVESTIGATION

The aims of the investigation were as follows:

1. To quantify the degree of soft tissue changes that occur in non-high mandibular plane angle and high mandibular plane angle smiling patients as a result of extraction orthodontic treatment.
2. To identify patterns of topographical soft tissue changes that occur in the peri-oral region of smiling patients consequent to extraction orthodontic treatment.
3. To compare the patterns of soft tissue changes that occur in the non-high mandibular plane angle and high mandibular plane angle smiling patients with extraction orthodontic treatment.

CHAPTER 4

MATERIALS AND METHODS

4.1 Subject Selection

Prior to data collection, the research design was approved by the Temple University Institutional Review Board (IRB). Subjects were chosen from a pool of patients treated in the Podray Orthodontic Clinic at the Temple University, Maurice H. Kornberg School of Dentistry (Philadelphia, PA). Selection was based on patients having a pre-treatment (initial) 3dMD image taken during their records appointment, completed comprehensive orthodontic treatment, and having a post-treatment (final) 3dMD image. Subjects must have been diagnosed with a unilateral or bilateral end-on (or more severe) Class II canine or molar, and must have been treated to establish a Class I relationship. Subjects were between ages 11 and 18 years old before beginning phase II treatment. Patients with skeletal deformities were excluded from the sample.

The sample consisted of 36 individuals (19 males and 17 females). Subjects were first divided into an extraction group (these patients had either two or four premolars extracted for orthodontic treatment, n = 14) and a non-extraction group (n= 22). These groups were then subdivided into high angle patients and non-high angle patients. Subjects with a mandibular plane angle (measured as the angle created by a line from Menton to Gnathion and the Frankford Horizontal) 28^{o} or greater were classified as high angle. The four groups of subjects are demonstrated as follows:

Table 1. Experimental groups

	High angle	Non-high angle
Extractions	**Group HE** n = *8*	**Group LE** n = *6*
Non-extraction	**Group HN** n = *7*	**Group LN** n =*15*

HE - High angle extraction patients
HN - High angle non-extraction patients
LE - Non-high angle extraction patients
LN - Non-high angle non-extraction patients

4.2 Image Acquisition

The 3dMD Face system (3dMD, Atlanta, Georgia) is a commercially available stereophotogrammetric technology. It is used routinely in the orthodontic department at Temple University for 3D soft tissue imaging. Patients were positioned in front of the camera to capture the area from above the clavicle to the top of the head, and from ear to ear. Patients were instructed to look at a mounting on the wall ahead of them to maintain natural head position. One image was taken in repose and one image was taken while smiling. To ensure capturing a natural and reproducible smile, patients were asked to bite their teeth together lightly, smile, and say “cheese” (Zachrisson, 1998). After acquisition, images were verified for lack of voids or distortion. Poor images were taken again.

4.3 Image Manipulation

All images were saved as .tsb files, and were manipulated using the 3dMD Vultus software (3dMD, Atlanta, GA.) An Intel ® Core ™ i5-2400 CPU @ 3.10GHz, 3101 Mhz processor and NVIDIA GeForce GT 440 graphics card (NVIDIA, Santa Clara, CA), running on Microsoft Windows 7 Professional (Microsoft Corp, Redmond, WA) were used to visualize, refine, measure, and superimpose images.

4.4 Superimposition and Registration

The procedure used for superimposition and registration was adapted from a study by Devin Croft at Temple University. Please refer to the cited documents (Croft, 2008; Franklin, 2010) for stepwise instructions.

All images were first cleaned up to remove extraneous data, such as clothing and patient napkins. These images were saved as .tbs files and became the working images for following steps.

The refined smile image was then oriented along the X, Y, and Z axes by manual manipulation. The final smile image was then manually superimposed, in three planes of space, on the pre-treatment image. Once the position of the second image approximated that of the first, the registration function of the Patient Software was used to more accurately align the selected regions of the nasal bridge, forehead, and temples. Root mean square (RMS) values were accepted only if this value was less than 0.5. If the RMS value was not less than 0.5, the procedure was repeated.

Images (.jpeg) of frontal and profile views of the superimposition were saved as data for each subject.

4.5 Topographical Map

The software tool for measuring the distance between two surfaces was used to generate a color histogram for each patient. The initial image served as our reference surface, and the final image was selected for the difference surface.

4.6 *Volume calculations*

Volume was calculated for each image, and changes in volume during treatment were calculated using the software volume calculation tool. The radius software tool was used to calculate volume. We limited our volume calculations to the area immediately surrounding the lips, which we defined as the distance from excanthion to excanthion. First, a sphere was generated with a diameter equal to the distance from excanthion to excanthion. Once this sphere was generated, it was centered in all three planes of space at the midline of the vermillion border. The volume of any 3dMD image that was within this sphere could then be calculated. The volume of the initial 3dMD image within this sphere was subtracted from the volume of the final 3dMD image within this same sphere. Thus, a value in cc's could be reported as the volume difference between initial and final 3dMD images.

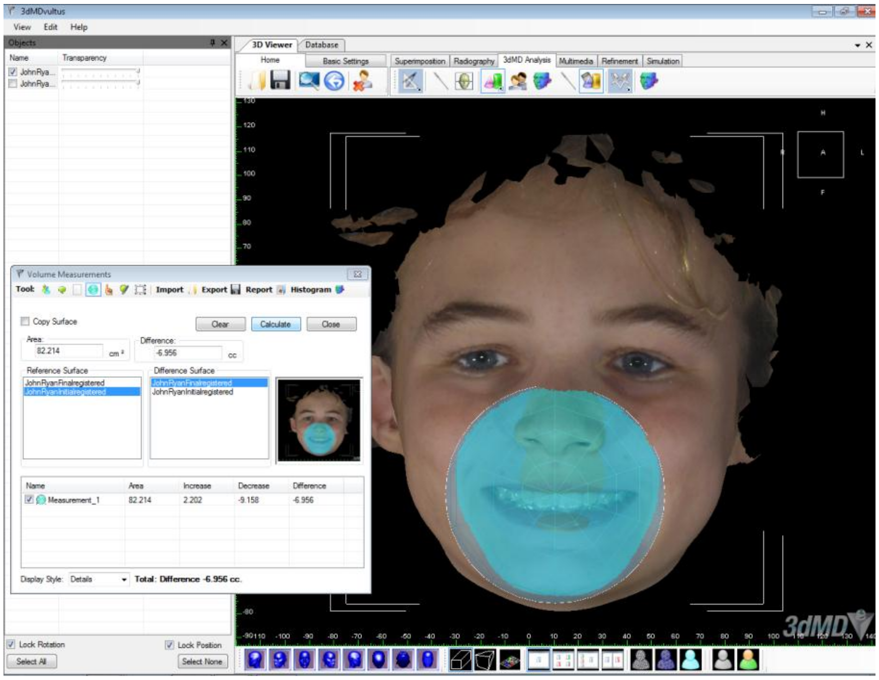


Figure 1. Volume Calculations
See the blue sphere centered at the midline of the upper lip. We calculated the volume of the 3dMD image within this sphere.

4.6 Error Analysis

Three separate superimpositions were performed for one randomly selected subject in each of the four groups to test the reliability of the 3dMD Patient Software. These serial superimpositions were done at least 24 hours apart, and were performed by the same operator who performed all computer manipulations throughout the study. Similarity was based on the relative color pattern of the histogram and on the RMS value.

4.7 Quantitative Analysis

Absolute changes were estimated using the method described by both Croft (2008) and Franklin (2010). The range of color function, located in the pop-up display window, permitted manual adjustment of the upper and lower color limits. The color range was manually adjusted and set at a level just before dark areas of burn-through appeared in the histogram. This function assigns the colors of the histogram to a quantitative surface change, measured in millimeters. The range of change (mm) for each subject group was recorded for the following areas: commissures, cheeks, lips at the midline, chin (pogonion), and tip of nose.

A Shapiro Wilke's test for normality was performed on all four groups to check for normal distribution. An equal variance test was performed for each of the eight cephalometric landmarks. One-way ANOVA was used to determine differences between the groups for all variables. Changes between groups were also tested for statistical significance using the Tukey-HSD test.

In addition to comparisons between different experimental groups, all bilateral points (cheeks and commissures) were compared to their contralateral partner (right commissure to left commissure) to evaluate symmetry.

4.8 Qualitative Analysis

Positive and negative surface changes were identified for each subject, based upon his or her histogram. Positive changes were indicated by warmer colors, such as pink and purple. These colors correspond to areas where the face came forward, towards the viewer of the histogram. Cooler colors, such as green, indicate negative changes. Correspondingly, these were surfaces that moved back, away from the computer screen and the viewer. These changes were not absolute, but rather relative to each of the 36 subjects' initial image.

Once the histograms were created, the following eight points were identified on each histogram: right commissure, left commissure, midline of the upper lip at the vermillion border, midline of the lower lip at the vermillion border, chin (pogonion), tip of nose, right cheek, and left cheek. The cheek point was measured at the intersection of the vertical line drawn down from excanthion (perpendicular to true horizontal) and the horizontal line drawn from the tip of the nose (parallel to true horizontal). Each of these points was then assigned a value based on the intensity of the color that was seen at that point. As seen below, a value of +++ was assigned to points displaying the highest intensity of red, and --- was assigned to points displaying the highest intensity of green.

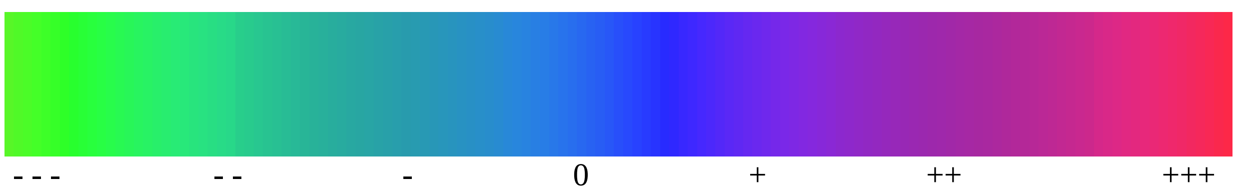


Figure 2. Histogram color spectrum
Values ranging from - - - to + + + were assigned based on the color seen at that landmark.

A color-coded table was created for each of the four experimental groups. The investigators then used these color-coded tables to evaluate clustering of like colors. The patterns and trends manifested through this form of data collection provided observational results to complement our quantitative results. An example of a color-coded table is seen below:

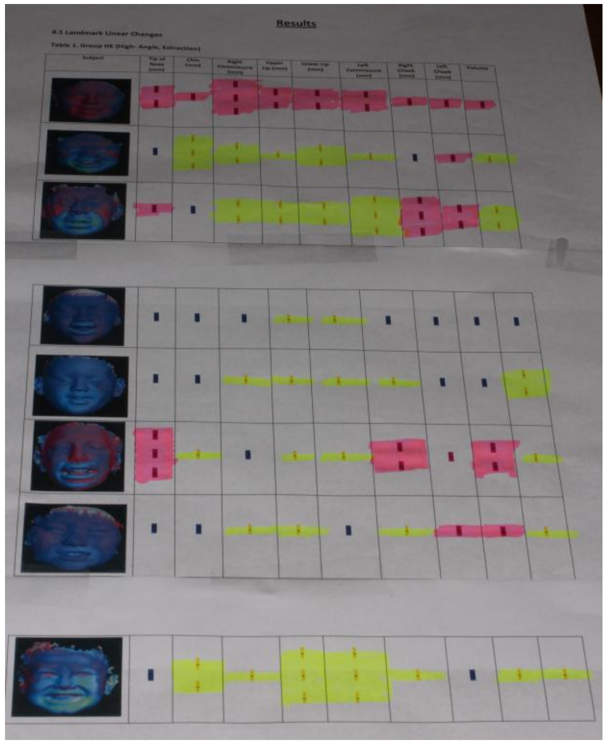


Figure 3. Qualitative color-coded table
An example of the qualitative color-coded tables used to identify trends in data. Note that more yellow is seen on this table than blue or pink.

Volume was assessed in a similar manner. Categories were assigned to volume based on the following scale:

Table 2. Categorical volumetric values

Volume Range (cc)s	Categorical Value
Greater than 25	+++
15 to 25	++
5 to 15	+
-5 to 5	0
-15 to -5	-
-15 to -25	--
Less than -25	---

CHAPTER 5

RESULTS

5.1 Quantitative Linear and Volumetric Changes

The table below exhibits the mean surface changes and standard deviations for each identified landmark. For data on all 36 individual subjects, please refer to Appendix A.

Table 3. Mean surface changes and standard deviations

Group	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)
HE	0.06±1.31	-0.37 ± 3.11	-2.36 ±3.18	-2.74±1.72
LE	1.03±1.65	2.11±5.02	-0.10±2.54	-2.45±3.00
HN	0.83±1.00	1.69±3.10	2.45±3.01	-0.03±3.17
LN	0.23±0.93	1.39±2.01	0.10±1.50	-1.52±1.71

Group	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
HE	-0.77 ±2.06	-1.60 ±3.52	0.69±1.45	0.08±1.87
LE	1.00±3.30	0.42±2.75	-0.09±2.08	0.26±1.34
HN	2.50±2.09	1.94±4.24	-0.78±0.76	-1.31±1.07
LN	0.68±1.21	-0.27±1.64	-0.09±1.28	-0.33±1.46

All four groups show an advancement of the tip of the nose, with the LE group showing the largest advancement. The chin retracts by an average of 0.37 mm in the HE group, but advances in the three other groups. All four groups also have significant standard deviations in chin position, the highest being 5.02 mm in the LE group. The HE group shows the greatest retraction of the right commissure, while the HN group shows the greatest increase, with changes ranging from -2.36 mm to 2.45 mm. All four experimental groups display retraction of the upper lip. The extraction groups show more retraction than the non-extraction groups. Interestingly, the HE was the only group in which the lower lip shows retraction. Conversly, the HN group shows the largest advancement in lower lip position. Following in the same pattern, the HE group also shows a 1.60 mm retraction of the left commissure, while the HN group has the largest average advancement of the left commissure. Changes in right cheek position range from -0.78 mm to 0.69 mm, and changes in the left cheek position range from -1.31 mm to 0.26 mm. The HN group shows the greatest cheek retraction of both the right and left cheek.

Two pairwise comparisons are noted as statistically significant. First, the change seen in the lower lip between HE group and HN group is statistically significant. There is a mean difference of 3.26 mm between the 0.77 mm retraction in the lower lip seen in the HE group and the 2.50 mm advancement in lower lip position seen in the HN group. In addition, a pairwise comparison of the right commissure between these same two groups is also statistically significant. An absolute difference of 4.80 mm exists between the right commissure position of the HE and HN group.

No group shows statistically significant changes when comparing right and left side landmarks within the same group.

The Shapiro-Wilke's test for normality shows abnormal distribution among all four groups. The upper lip is not normally distributed in the HE group. The upper lip and right cheek are not normally distributed in the LE group. The left commissure is not normally distributed in the HN group, and the tip of nose does not show normal distribution in the LN group.

Changes in volume range from -9.17 cc to 4.83 cc. The HE group shows the largest decrease in volume, while the HN group shows the largest increase. The LE and HN group have large standard deviations of 20.65 and 10.12, respectively. No statistical significance in the differences was found in these results. The table below shows the average volume change for all groups:

Table 4. Mean volume changes

Group	Average Volume (cc)
HE	-9.17 ± 9.78
LE	0.68 ± 20.65
HN	4.83 ± 10.12
LN	-0.04 ± 5.82

5.2 Qualitative results

Below are our qualitative results for each of the 36 subjects. Histograms of all subjects can be found in Appendex B. Color-coded result tables can be found in Appendex C.

Table 5. Group HE (High-Angle, Extraction)

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
HE1	++	+	+++	++	++	++	+	+
HE2	0	---	--	-	--	-	0	+
HE3	+	0	--	--	--	---	+++	++
HE4	0	0	0	-	-	0	0	0
HE5	0	0	-	-	-	-	0	0
HE6	+++	-	0	-	-	++	+	++
HE7	0	0	-	-	0	-	+	+
HE8	0	--	-	---	---	-	0	-

Table 6. Group LE (Low-Angle, Extraction)

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
LE1	0	--	0	-	--	0	-	-
LE2	0	-	-	-	-	-	-	-
LE3	0	0	0	0	0	0	0	0
LE4	0	0	0	-	-	-	0	0
LE5	+	++	0	0	0	0	-	-
LE6	+	0	-	-	-	-	0	0

Table 7. Group HN (High-Angle, Non-extraction)

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
HN1	0	0	+	0	-	0	0	-
HN2	+	0	0	-	-	-	-	-
HN3	+	++	0	0	-	+	-	-
HN4	0	++	+	0	+	+	0	0
HN5	++	0	+	+	++	+	0	0
HN6	++	++	+	+	++	0	+	+
HN7	0	+	++	+	+	++	-	-

Table 8. Group LN (Low-Angle, Non-extraction)

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
LN1	0	0	-	0	-	-	0	0
LN2	0	0	0	0	-	0	0	0
LN3	0	0	+	+	+	+	0	0
LN4	0	0	0	0	+	0	0	0
LN5	++	++	+	+	++	+	0	0
LN6	+++	+	+++	0	0	+++	+	0
LN7	0	0	-	-	-	-	0	0
LN8	0	0	0	0	0	0	0	0
LN9	+	++	0	+	++	0	+	+
LN10	+	0	0	0	0	+	+	+
LN11	+	++	0	0	0	0	0	0
LN12	+	+	+	+	+	+	+	0
LN13	0	0	0	0	0	0	0	0
LN14	0	0	0	0	0	0	0	0
LN15	0	0	0	0	0	0	-	-

The linear qualitative results are summarized in the following table. Retraction refers to surfaces moving away from the viewer. Fullness refers to surfaces moving towards the viewer.

Table 9. Qualitative surface changes

Group	**Nose**	**Chin**	**Right Commissure**	**Upper Lip**
HE	Fullness	No change	Slight Retraction	Retraction
LE	No change	No change	Retraction	Retraction
HN	Fullness	Fullness	Fullness	No change
LN	Slight fullness	Slight fullness	No change	No change
Group	**Lower Lip**	**Left Commissure**	**Right Cheek**	**Left Cheek**
HE	Retraction	Slight retraction	Fullness	Fullness
LE	Retraction	Retraction	No change	No change
HN	Slight fullness	Fullness	Slight retraction	Slight retraction
LN	Slight fullness	No change	No change	No change

Tabled below are the volumetric results for all 36 subjects:

Table 10. Qualitative volume changes

Subject	Volume	Subject	Volume	Subject	Volume	Subject	Volume
LN1	-	LE1	0	HE1	+	HN1	0
LN2	-	LE2	--	HE2	-	HN2	-
LN3	+	LE3	0	HE3	--	HN3	0
LN4	0	LE4	0	HE4	0	HN4	+
LN5	0	LE5	+++	HE5	--	HN5	+
LN6	+	LE6	-	HE6	-	HN6	0
LN7	-			HE7	-	HN7	++
LN8	0			HE8	-		
LN9	0						
LN10	0						
LN11	-						
LN12	0						
LN13	+						
LN14	0						
LN15	+						

Very little change is noted in the LN and the LE groups. In the HE group, a consistent pattern of decreasing volume can be observed. In the HN group, a pattern of increasing volume is noted.

5.3 Error Analysis

Serial superimpositions were completed for a randomly selected subject in each of the four experimental groups. The RMS values for all subsequent superimpositions were within 0.1 mm, and the histograms created at each interval were nearly identical, showing similar patterns of facial change at all three superimposition time points.

CHAPTER 6

DISCUSSION

6.*1 Quantitative Discussion*

Despite a plethora of studies on the effects of extraction on the repose face, to our knowledge, this is the first comprehensive study to examine the effects of extraction on the smiling face in 3D. As hypothesized, premolar extractions cause different soft tissue changes on the smiling face than not extracting premolars. Two comparisons show statistical significance: the lower lip changes and the right commissure changes between the HE group and the HN group.

The lower lip and commissure changes found in our study corroborate similar studies of the repose face (Papasikos, 2013; Bishara et al., 1995; James, 1998). It has been shown that extraction treatment causes lower lip retraction, and the same seems to be true when these patients smile.

Interestingly, this pattern was only seen in high angle patients. The low angle extraction and non-extraction groups showed little difference between upper lip change, lower lip change, right and left commissure change, and right and left cheek change. Although not statistically significant, the two low angle groups differed in volume change by less than 1 cc, whereas the high angle groups differed in volume change by 15 cc. This leads the investigators to believe that low angle patients are less responsive to extraction treatment, and that high angle patients have the potential for greater smiling changes consequent to treatment.

Although these two pairwise comparisons did show statistical significance, the quantitative changes were somewhat sporadic. They must be viewed with a skeptical eye. The data set we compiled shows extreme individual variation from subject to subject. All landmarked surface changes showed large standard deviations, as high as $\pm$ 5.02, suggesting that individual growth may play a larger role in treatment outcome than a clinician's treatment plan. The abnormal distribution of data seen in all four experimental groups also indicates robust individual variability.

The current literature supports the fact that treatment mechanics will dictate the final position of soft tissue. More or less lip retraction can be achieved by using more or less posterior anchorage. In our sample size, it was not possible to control for treatment mechanics, anchorage considerations, crowding, or growth. Thus, the experimental groups were innately heterogeneous.

An uncontrolled variability in this investigation was the ability of our patients to reproduce a smile. Ample evidence suggests that smiles reproduced at different appointments show little differences. In our experience, however, it was still difficult to capture smiling 3dMD images of many of our subjects, and ensure that all individuals were smiling naturally. Our small sample size magnifies all of these small smiling inconsistencies. A larger sample size will be needed in future studies to increase the power of the study and decrease the possibility of type 1 error.

6.2 Qualitative Discussion

As previously described, our data set had large levels of abnormality and variation. Because of this, statistics alone do not do this data set justice. A qualitative approach to data analysis allows for human discretion, and offers unique insights into the patterns and trends of what otherwise might be considered insignificant data. The experimenters believe that qualitative analysis, particularly in studies of esthetics of the human smile, provides different, if not greater, insight than other methods.

Much of our qualitative results echo our statistical findings. The two statistically significant findings can also be seen qualitatively. All but one subject (HE1) in the HE group experiences either retraction or no change of the right commissure. This contrasts sharply with the HN group, in which all subjects show either no change or fullness of the right commissure. Similarly, all but one subject (again, HE1) also experiences either retraction or no change of the lower lip. Conversely, all subjects in the HN group, except HN2, show either no change or an increase in fullness in the upper lip.

As expected, the nose and chin either show no change or they show notable fullness in all groups. This is expected, as all patients are between 11-18 years old, and within peak growing years.

Only a qualitative approach allows one to see the changes occurring at the lips and commissures. Both extraction groups display retraction of the commissures and the lips. Both non-extraction groups show either no change or a fullness of these four points. Therefore, the lip position of a smiling patient treated with extraction changes similar to that of a repose patient.

On the other hand, the cheeks behave in an opposite manner. The cheeks of the HE patients increase in fullness, while the cheeks of the HN patients show slight retraction. This seems counterintuitive. One might expect the cheeks of the extraction patient to follow in suit with the lips and be retracted. An explanation for this is difficult. Perhaps once lip drape is decreased, the facial muscles used in smiling have an increase in mobility and motility in the cheek area, and thus become more prominent in this region. Further studies are needed to help explain this surprising finding.

An unexpected finding in this study was how symmetrical the smile images were in groups before and after treatment. No bilateral points were shown to have changed at statistically significant rates. In the HE group, the right commissure and left commissure both slightly retracted. In the LE group these points both retract. In the HN group, both points increase in fullness, and in the LN group, both commissures show no change. In the HE group, both cheeks increased fullness. In the LE group, both cheeks show no change. In the HN group, both cheeks show slight retraction. In the LN group, both cheeks showed no change.

Many patients seeking orthodontic treatment have asymmetric smiles, often due to lip hyperplasticity. What our results suggest is that these asymmetries are unaffected by orthodontic treatment. Patients who appear to have asymmetric smiles in their initial records will most likely continue to have these asymmetric smiles in their final photos. The commissures and cheeks on both the right and left side of the face seem to change in an identical manner. Orthodontic treatment does not appear to be able to change or correct smile asymmetries.

Qualitative volume comparisons parallel our quantitative findings. Few changes are seen in the LN and LE groups. The HE group shows an increase in volume, while the HN group shows a decrease in volume. We attribute this pattern again to the increased sensitivity of high angle patients to extraction treatment.

Jacy Papasikos conducted a concurrent thesis on the soft tissue effects of extraction on a repose patient. On the following page, please find a compilation of these two soft tissue studies. As expected, the smiling and repose response of the upper and lower lips in all extraction groups is retraction of the soft tissue. The commissures, though somewhat variable in the low angle repose patients, also show this same trend of retraction in both smiling and repose. All high angle patients, treated with extraction or non-extraction, show a retraction of the right and left cheek when smiling and when in repose. This retraction might be due to a more vertical growth pattern, and less anterior-posterior growth in malar region.

Also remarkable are the upper lip changes in non-extraction treatment. Papasikos found that the upper lip retracted in non-extraction patients in repose. Our findings contradict this- there was no upper lip change when these patients were smiling. Therefore, although change was noted in the repose face, it's clear that these changes do not always translate to a smile.

Most interestingly, soft tissue differences of the face due to treatment, growth, or both, seem to disappear upon smiling, with the exception of the lips

The following table shows preliminary data of the 3 dimensional changes incurred during orthodontic treatment, and might be useful as a clinical guide.

Table 11. Preliminary clinical guidelines for soft tissue changes

Group	Facial Expression	Nose	Chin	Right Commissure	Upper Lip	Lower Lip	Left Commissure	Right Cheek	Left Cheek
HE	Smiling	Fullness	No change	Slight retraction	Retraction	Retraction	Slight retraction	Fullness	Fullness
	Repose	Fullness	Variable	Retraction	Retraction	Retraction	Retraction	Variable	Variable
LE	Smiling	No change	No change	Retraction	Retraction	Retraction	Retraction	No change	No change
	Repose	Fullness	Retraction	Variable	Retraction	Retraction	Variable	Variable	Variable
HN	Smiling	Fullness	Fullness	Fullness	No change	Slight fullness	Fullness	Slight retraction	Slight retraction
	Repose	Fullness	Variable	No change	Retraction	Variable	No change	Retraction	Retraction
LN	Smiling	Slight fullness	Slight fullness	No change	No change	Slight fullness	No change	No change	No change
	Repose	Fullness	Fullness	Variable	Retraction	Variable	Variable	Variable	Variable

CHAPTER 7

CONCLUSIONS

A quantitative and qualitative analysis of the 3D histograms reveals the following patterns:

1. Soft tissue changes differed between extraction and non-extraction patients in the high angle group.
2. In contrast, changes resulting from treatment type (extraction vs. non-extraction) were similar in low angle groups.
3. The lower lip and right commissure of high angle extraction patients show statistically significant changes when compared to high angle non-extraction patients.
4. A greater change can be expected in high angle patients than low angle patients when treated with extractions.
5. Soft tissue smile changes due to orthodontic treatment tend to be symmetrical.
6. The lip changes seen in an extraction patient upon smiling are very similar to those changes seen in the same patient in repose.
7. Soft tissue differences of the face due to treatment, growth, or both, seem to disappear upon smiling, with the exception of the lips.
8. Large individual variation exists when viewing soft tissue changes on 3D histograms. Qualitative assessment of changes in the smile is a more appropriate method for identifying these patterns of change than quantitative assessment.

REFERENCES CITED

Ackerman, J. L., et al. "A morphometric analysis of the posed smile." *Clinical orthodontics and research* 1.1 (1998): 2.

Ackerman, Marc B. and James L. Ackerman. "Smile analysis and design in the digital era." *Journal of Clinical Orthodontics* 36.4 (2002): 221-236.

Angle, Edward H. The treatment of malocclusion of the teeth. 7th ed. Philadelphia: SS White; 1907:64.

Arcuri , Andrew. " The relationship of the eyes and periorbital facial tissues to smile esthetics: A qualitative analysis of dynamic facial expression." *MS thesis Temple Univeristy*, 2004. Print.

Athanasiou, Anthanasios E. "Orthodontic cephalometry." *American Journal of Orthodontics and Dentofacial Orthopedics* 111.4 (1997): 458-458.

Baldwin, DeWitt C. "Appearance and aesthetics in oral health." *Community dentistry and oral epidemiology* 8.5 (1980): 244-256.

Beattie, John R., David E. Paquette, and Lysle E. Johnston Jr. "The functional impact of extraction and nonextraction treatments: a long-term comparison in patients with "borderline," equally susceptible Class II malocclusions." *American Journal of Orthodontics and Dentofacial Orthopedics* 105.5 (1994): 444-449.

Bishara, Samir E., David M. Cummins, and Jane R. Jakobsen. "The morphologic basis for the extraction decision in Class II, division 1 malocclusions: a comparative study." *American Journal of Orthodontics and Dentofacial Orthopedics* 107.2 (1995): 129-135.

Bishara, Samir E., and Jane R. Jakobsen. "Profile changes in patients treated with and without extractions: assessments by lay people." *American journal of orthodontics and dentofacial orthopedics* 112.6 (1997): 639-644.

Bishara, Samir E., et al. "A computer assisted photogrammetric analysis of soft tissue changes after orthodontic treatment. Part I: Methodology and reliability." *American journal of orthodontics and dentofacial orthopedics* 107.6 (1995): 633.

Bishara, Samir E., et al. "Dentofacial and soft tissue changes in Class II, division 1 cases treated with and without extractions." *American journal of orthodontics and dentofacial orthopedics* 107.1 (1995): 28.

Boley, J. C., et al. "Facial changes in extraction and nonextraction patients." *The Angle Orthodontist* 68.6 (1998): 539-546.

Bowman, S. Jay, and Lysle E. Johnston Jr. "The esthetic impact of extraction and nonextraction treatments on Caucasian patients." *The Angle Orthodontist* 70.1 (2000): 3-10.

Bowman, S. Jay. "More than lip service: facial esthetics in orthodontics." *The Journal of the American Dental Association* 130.8 (1999): 1173-1181.

Bravo, Luis Alberto. "Soft tissue facial profile changes after orthodontic treatment with four premolars extracted." *The Angle orthodontist* 64.1 (1994): 31-42.

Carlos Quintero, Juan, et al. "Craniofacial imaging in orthodontics: historical perspective, current status, and future developments." *The Angle Orthodontist* 69.6 (1999): 491-506.

Christenson, G. *Clin Res Assoc. Newsletter.* 5.1 (1981)

Croft, Devin. "Application of 3dMD Images to the Study of Orthodontic Treatment Effects." *MS thesis Temple University,* 2008. Print.

Daniels, Adam S., Jason D. Seacat, and Marita Rohr Inglehart. "Orthodontic treatment motivation and cooperation: a cross-sectional analysis of adolescent patients' and parents' responses." *American Journal of Orthodontics and Dentofacial Orthopedics* 136.6 (2009): 780-7.

Darwin, Charles, and Gillian Beer. *The origin of species*. Oxford University Press,1951.

Darwin, Charles. *The expression of the emotions in man and animals*. Oxford University Press, USA, 1998.

Dion, Karen K. "Physical attractiveness and evaluation of children's transgressions."*Journal of Personality and Social Psychology* 24.2 (1972): 207 213.

Dion, Karen, Ellen Berscheid, and Elaine Walster. "What is beautiful is good." *Journal of personality and social psychology* 24.3 (1972): 285-290.

Dong, Jin-Keun, et al. "The esthetics of the smile: a review of some recent studies." *The International journal of prosthodontics* 12.1 (1999): 9.

Dorsey, Joseph, and Karen Korabik. "Social and psychological motivations fo orthodontic treatment." *American Journal of Orthodontics* 72.4 (1977): 460 467.

Drobocky, Oles B., and Richard J. Smith. "Changes in facial profile during orthodontic treatment with extraction of four first premolars." *American Journal of Orthodontics and Dentofacial Orthopedics* 95.3 (1989): 220-230.

Farkas, Leslie G. *Anthropometry of the head and face in medicine*. New York: Elsevier, 1981.

Farkas, Leslie G., William Bryson, and James Klotz. "Is photogrammetry of the face reliable?" *Plastic and Reconstructive surgery* 66.3 (1980): 346-355.

Farrow, Anthony L., Kourosh Zarrinnia, and Khosrow Azizi. "Bimaxillary protrusion in black Americans—an esthetic evaluation and the treatment considerations." *American Journal of Orthodontics and Dentofacial Orthopedics* 104.3 (1993): 240-250.

Franklin, Brittney. "3dmd system analysis of facial soft tissue changes with premolar extraction orthodontic treatment in high and average mandibular plane angle patients. *MS thesis Temple University,* 2009. Print.

Frazier, P. Jean, et al. "Provider expectations and consumer perceptions of the importance and value of dental care." American Journal of Public Health 67.1(1977): 37-43.

Gavan, J. A., S. L. Washburn, and P. H. Lewis. "Photography: an anthropometric tool." *American journal of physical anthropology* 10.3 (1952): 331-354.

Ghaffar, Farhana, and Mubassar Fida. "Effect of extraction of first four premolars on smile aesthetics." *The European Journal of Orthodontics* 33.6 (2011): 679-683.

Gillen, Robert J., et al. "An analysis of selected normative tooth proportions." *The International journal of prosthodontics* 7.5 (1994): 410.

Halazonetis, Demetrios J. "Acquisition of 3-dimensional shapes from images." *American journal of orthodontics and dentofacial orthopedic.* 119.5 (2001): 556.

Hall, Denise, et al. "The perception of optimal profile in African Americans versus white Americans as assessed by orthodontists and the lay public." *American Journal of Orthodontics and Dentofacial Orthopedics* 118.5 (2000): 514-525.

Heike, Carrie L., et al. "3D digital stereophotogrammetry: a practical guide to facial image acquisition." *Head & face medicine* 6.1 (2010): 18.

Heike, Carrie L., et al. "Picture perfect? Reliability of craniofacial anthropometry using three-dimensional digital stereophotogrammetry." *Plastic and reconstructive surgery* 124.4 (2009): 1261-1272.

Henson, Scott T., et al. "Influence of dental esthetics on social perceptions of adolescents judged by peers." *American Journal of Orthodontics and Dentofacial Orthopedics* 140.3 (2011): 389-395.

Hulsey, Charles M. "An esthetic evaluation of lip-teeth relationships present in the smile." *American journal of orthodontics* 57.2 (1970): 132-144.

Incrapera, Angela K., et al. "Soft tissue images from cephalograms compared with those from a 3D surface acquisition system." *The Angle Orthodontist* 80.1 (2010): 58-64.

Işıksal, Erdal, Serpil Hazar, and Sercan Akyalçın. "Smile esthetics: perception and comparison of treated and untreated smiles." *American journal of orthodontics and dentofacial orthopedics* 129.1 (2006): 8-16.

Ismail, S. F. H., J. P. Moss, and R. Hennessy. "Three-dimensional assessment of the effects of extraction and nonextraction orthodontic treatment on the face." *American journal of orthodontics and dentofacial orthopedics* 121.3 (2002): 244-256.

James, Richard Don. "A comparative study of facial profiles in extraction and nonextraction treatment." *American journal of orthodontics and dentofacial orthopedics* 114.3 (1998): 265-276.

Jenny J, et al. *"*Relationship between dental aesthetics and attributions of self-confidence*."* *Journal of Dental Research* 69 (1990): 204.

Jenny J, Proshek JM. "Visibility and prestige of occupations and the importance of dental appearance." *Journal of the Canadian Dental Association*. 52.12 (1986): 987-9.

Johnson, Darryl K., and Richard J. Smith. "Smile estheties after orthodontic treatment with and without extraction of four first premolars." *American Journal of Orthodontics and Dentofacial Orthopedics* 108.2 (1995): 162-167.

Johnston, Darren James, et al. "Are facial expressions reproducible?" *The Cleft palate craniofacial journal* 40.3 (2003): 291-296.

Kau, Chung How, et al. "Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery." *The International Journal of Medical Robotics and Computer Assisted Surgery* 3.2 (2007): 97-110.

Kim, Eunkoo, and Anthony A. Gianelly. "Extraction vs nonextraction: arch widths and smile esthetics." *The Angle orthodontist* 73.4 (2003): 354-358.

Kokich, Vincent O., H. Asuman Kiyak, and Peter A. Shapiro. "Comparing the perception of dentists and lay people to altered dental esthetics." *Journal of Esthetic and Restorative Dentistry* 11.6 (1999): 311-324.

Landy, David, and Harold Sigall. "Beauty is talent: Task evaluation as a function of the performer's physical attractiveness." *Journal of Personality and Social Psychology* 29.3 (1974): 299.

Linn, Erwin L. "Social meanings of dental appearance." *Journal of health and human behavior* (1966): 289-295.

Liu, Zhijian, Colman McGrath, and Urban Hägg. "The impact of malocclusion/orthodontic treatment need on the quality of life: a systematic review." *The Angle orthodontist* 79.3 (2009): 585-591.

Locher, Paul J. "A measure of the information content of visual art stimuli for studies in experimental aesthetics." *Empirical Studies of the arts* 13.2 (1995): 183-191.

Lombardi, Richard E. "The principles of visual perception and their clinical application to denture esthetics." *The Journal of prosthetic dentistry* 29.4 (1973): 358-382.

Luppanapornlarp, Suwannee, and Lysle E. Johnston Jr. "The effects of premolar extraction: a long-term comparison of outcomes in “clear-cut” extraction and nonextraction Class II patients." *The Angle Orthodontist* 63.4 (1993): 257-272.

Mahshid, Minoo, et al. "Evaluation of “golden proportion” in individuals with an esthetic smile." *Journal of Esthetic and Restorative Dentistry* 16.3 (2004): 185-192.

Miller, C. J. "The smile line as a guide to anterior esthetics." *Dental Clinics of North America* 33.2 (1989): 157.

Paquette, David E., John R. Beattie, and Lysle E. Johnston. "A long-term comparison of nonextraction and premolar extraction edgewise therapy in “borderline” Class II patients." *American Journal of Orthodontics and Dentofacial Orthopedics* 102.1 (1992): 1-14.

Parekh, S., et al. "The acceptability of variations in smile arc and buccal corridor space." *Orthodontics & craniofacial research* 10.1 (2007): 15-21.

Parr, Lisa A., and Bridget M. Waller. "Understanding chimpanzee facial expression: insights into the evolution of communication." *Social cognitive and affective neuroscience* 1.3 (2006): 221-228.

Passia, N., M. Blatz, and J. R. Strub. "Is the smile line a valid parameter for esthetic evaluation? A systematic literature review." *The European journal of esthetic dentistry: official journal of the European Academy of Esthetic Dentistry* 6.3 (2011): 314.

Patzer, Gordon L. "Self Esteem and Physical Attractiveness." *Journal of Esthetic and Restorative Dentistry* 7.6 (1995): 274-276.

Peck, Harvey, and Sheldon Peck. "A concept of facial esthetics." *The Angle orthodontist* 40.4 (1970): 284-317.

Peck, Sheldon, and Leena Peck. "Selected aspects of the art and science of facial esthetics." *Seminars in orthodontics*. Vol. 1. No. 2. WB Saunders, 1995.

Peck, Sheldon, Leena Peck, and Matti Kataja. "Some vertical lineaments of lip position." *American Journal of Orthodontics and Dentofacial Orthopedics* 101.6 (1992): 519-524.

Peck, Sheldon, Leena Peck, and Matti Kataja. "The gingival smile line." *The Angle Orthodontist* 62.2 (1992): 91-100.

Perkins, Daniel F., and Richard M. Lerner. "Single and multiple indicators of physical attractiveness and psychosocial behaviors among young adolescents." *The Journal of Early Adolescence* 15.3 (1995): 269-298.

Proffit, William R., Henry W. Fields Jr, and David M. Sarver. *Contemporary orthodontics*. Mosby, 2006.

Rigsbee III, O. H., T P. Sperry, and E. A. BeGole. "The influence of facial animation on smile characteristics." *The International journal of adult orthodontics and orthognathic surgery* 3.4 (1988): 233.

Rigsbee, O. H., T. P. Sperry, and E. A. BeGole. "The influence of facial animation on smile characteristics." *The International journal of adult orthodontics and orthognathic surgery* 3.4 (1988): 233.

Ross, Michael B., and John Salvia. "Attractiveness as a biasing factor in teacher judgments." *American Journal of Mental Deficiency* 80.1 (1975): 96.

Rushing, S. Everett, et al. "How dentists perceive the effects of orthodontic extraction on facial appearance." *The Journal of the American Dental Association* 126.6 (1995): 769-772.

Sarver, David M. "Principles of cosmetic dentistry in orthodontics: Part 1. Shape and proportionality of anterior teeth." *American journal of orthodontics and dentofacial orthopedics* 126 (2004): 749-53.

Sarver, David M. "The importance of incisor positioning in the esthetic smile: the smile arc." *American Journal of Orthodontics and Dentofacial Orthopedics* 120.2 (2001):98-111.

Sarver, David M., and Marc B. Ackerman. "Dynamic smile visualization and quantification: Part 2. Smile analysis and treatment strategies." *American journal of orthodontics and dentofacial orthopedics* 124.2 (2003): 116-127.

Sarver, David M., and Marc B. Ackerman. "Dynamic smile visualization and quantification: Part 1. Evolution of the concept and dynamic records for smile capture." *American journal of orthodontics and dentofacial orthopedics* 124.1 (2003): 4-12.

Sawyer, Adam R., Marlene See, and Charles Nduka. "Assessment of the reproducibility of facial expressions with 3-D stereophotogrammetry." *Otolaryngology—Head and Neck Surgery* 140.1 (2009): 76-81.

Schmidt, Karen L., and Jeffrey F. Cohn. "Human facial expressions as adaptations: Evolutionary questions in facial expression research." *American journal of physical anthropology* 116.S33 (2001): 3-24.

Scott, Steven H., and Lysle E. Johnston Jr. "The perceived impact of extraction and nonextraction treatments on matched samples of African American patients." *American journal of orthodontics and dentofacial orthopedics* 116.3 (1999): 352-358.

Shaw, W. C., et al. "The influence of dentofacial appearance on the social attractiveness of young adults." *American journal of orthodontics* 87.1 (1985): 21-26.

Sinko, K., et al. "Facial aesthetics and the assignment of personality traits before and after orthognathic surgery." *International journal of oral and maxillofacial surgery* 41.4 (2012): 469-476.

Snyder, Peter J., et al. "Charles Darwin's Emotional Expression “Experiment” and His Contribution to Modern Neuropharmacology." *Journal of the History of the Neurosciences* 19.2 (2010): 158-170.

Tjan, A. H., and Gary D. Miller. "Some esthetic factors in a smile." *The Journal of prosthetic dentistry* 51.1 (1984): 24.

Trumble, Angus. *A brief history of the smile*. Basic Books (AZ), 2004.

Vig, Robert G., and Gerald C. Brundo. "The kinetics of anterior tooth display." *The Journal of prosthetic dentistry* 39.5 (1978): 502.

Wahl, Norman. "Orthodontics in 3 millennia. Chapter 6: More early 20^{th} century appliances and the extraction controversy." *American journal of orthodontics and dentofacial orthopedics* 128.6 (2005): 795-800.

Walster, Elaine, et al. "Importance of physical attractiveness in dating behavior." *Journal of personality and social psychology* 4.5 (1966): 508-516.

Weinberg, Seth M., et al. "Anthropometric precision and accuracy of digital three-dimensional photogrammetry: comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry." *Journal of Craniofacial Surgery* 17.3 (2006): 477-483.

Wholley, Christopher J., and Michael G. Woods. "The effects of commonly prescribed premolar extraction sequences on the curvature of the upperand lower lips." *The Angle Orthodontist* 73.4 (2003): 386-395.

Wong, Julielynn Y., et al. "Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images." *The Cleft Palate Craniofacial Journal* 45.3 (2008): 232-239.

Zachrisson, Bjorn U. "Esthetic factors involved in anterior tooth display and the smile: vertical dimension." *Journal of Clinical Orthodontics* 32.7 (1998): 432-445.

APPENDIX A

INDIVIDUAL LINEAR CHANGES

Table 12. Group HE individual linear changes

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
HE1	1.44	0.7	3.67	1.46	0.48	1.06	-0.01	-1.39
HE2	-0.92	-6.4	-5.3	-3.23	-4.98	-3.24	1.22	1.97
HE3	-0.91	1.44	-5.62	-3.88	-1.35	-7.14	3.18	1.31
HE4	0.18	2.02	0.45	-3.19	1.42	1.74	-0.37	-0.35
HE5	-1.11	3.41	-4.86	-3.52	0.2	-4.53	1.67	2.83
HE6	2.47	-1.87	-2.31	-3.48	-0.05	3.39	-1.02	-1.78
HE7	-0.94	0.16	-3.15	-3.07	0.45	-2.83	1.55	0.41
HE8	0.3	-2.44	-1.72	-3.03	-2.3	-1.21	-0.69	-2.33
Mean	0.06	-0.37	-2.36	-2.74	-0.77	-1.60	0.69	0.08
Stnd Dev	1.31	3.11	3.18	1.72	2.06	3.52	1.45	1.87

Table 13. Group LE individual linear changes

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
LE1	0.41	0.51	0.22	-3.57	3.21	-0.19	0.06	-1
LE2	-0.41	-1.52	-3.46	-4.78	-3.1	-1.5	-4.14	-1.1
LE3	-0.21	0.97	1.09	-1.59	-2.37	1.08	0.99	0.51
LE4	0.42	0.61	1.2	-3.68	3.25	1.26	0.95	0.63
LE5	3.89	12.21	3.14	3.25	4.94	4.95	1.62	2.54
LE6	2.1	-0.11	-2.78	-4.35	0.08	-3.07	-0.04	-0.02
Mean	1.03	2.11	-0.10	-2.45	1.00	0.42	-0.09	0.26
Stnd Dev	1.65	5.02	2.54	3.00	3.30	2.75	2.08	1.34

Table 14. Group HN individual linear changes

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
HN1	-0.01	0.98	3.7	-1.39	0.59	0.59	-1.38	-2.08
HN2	0.9	-0.87	1.98	-4.46	4.73	-0.42	-0.3	-2.19
HN3	-0.07	0.79	-0.4	-2.52	1.07	1.64	-1.35	-2.44
HN4	-0.31	6.25	3.34	0.18	2.5	2.83	-0.47	-0.05
HN5	1.82	-1.39	1.2	1.03	0.99	-0.68	0.19	0
HN6	1.2	0.18	-0.77	1.61	1.58	-1.38	-0.25	-0.51
HN7	2.27	5.86	8.09	5.32	6.01	10.98	-1.88	-1.87
Mean	0.83	1.69	2.45	-0.03	2.50	1.94	-0.78	-1.31
Stnd Dev	1.00	3.10	3.01	3.17	2.09	4.24	0.76	1.07

Table 15. Group LN individual linear changes

Subject	Tip of Nose (mm)	Chin (mm)	Right Commissure (mm)	Upper Lip (mm)	Lower Lip (mm)	Left Commissure (mm)	Right Cheek (mm)	Left Cheek (mm)
LN1	-0.12	-0.46	-0.49	-2.69	-0.81	-1.39	0.93	1.3
LN2	-0.29	-1.08	-0.84	-3.49	-1.01	1.85	-1.98	-1.97
LN3	0.22	-0.68	-0.17	1.58	0.99	-0.34	0.22	1.09
LN4	2.18	0.47	-0.5	-2.13	1.74	-2.42	2.82	1.33
LN5	1.63	2.2	-1.01	-0.01	2.07	-2.23	-1.69	-1.29
LN6	0.32	-1.01	3.26	-3.05	-0.8	2.73	0.23	-1.52
LN7	-0.13	2.83	-2.87	-3.93	-0.79	-2.87	0.96	0.61
LN8	-0.03	2.29	0.93	-0.69	1.46	-0.39	-0.44	-0.04
LN9	-0.17	2.03	0.22	0.75	2.35	-1.04	0.7	1.21
LN10	0.05	-0.59	0.13	-1.29	0.23	0.83	0.33	0.39
LN11	1.83	4.06	1.98	0.68	2.17	1.01	0.06	-0.17
LN12	-0.41	4.34	0.99	-1.4	1.21	-0.93	0.39	-0.52
LN13	-1.23	4.4	1.71	-3.22	1.49	1.1	-1.06	-0.46
LN14	0.2	2.21	-0.93	-1.08	0.09	1	-0.88	-1.04
LN15	-0.53	-0.21	-0.93	-2.78	-0.23	-0.92	-1.87	-3.93
Mean	0.23	1.39	0.10	-1.52	0.68	-0.27	-0.09	-0.33
Stnd Dev	0.93	2.01	1.50	1.71	1.21	1.64	1.28	1.46

Table 16. Group HE individual volumetric changes

Subject	Volume (cc)
HE1	6.25
HE2	-12.09
HE3	-21.03
HE4	2.90
HE5	-20.33
HE6	-9.45
HE7	-7.34
HE8	-12.22
Mean	-9.17
Stnd Dev	9.78

Table 17. Group LE individual volumetric changes

Subject	Volume (cc)
LE1	-4.47
LE2	-18.92
LE3	-3.20
LE4	-2.14
LE5	40.93
LE6	-8.10
Mean	0.68
Stnd Dev	20.64

Table 18. Group HN individual volumetric changes

Subject	Volume (cc)
HN1	-0.26
HN2	-7.28
HN3	-4.05
HN4	9.28
HN5	9.25
HN6	4.07
HN7	22.80
Mean	4.83
Stnd Dev	10.12

Table 19. Group LN individual volumetric changes

Subject	Volume (cc)
LN1	-6.72
LN2	-7.41
LN3	5.88
LN4	2.52
LN5	0.46
LN6	5.67
LN7	-11.92
LN8	3.22
LN9	5.47
LN10	2.84
LN11	7.63
LN12	1.06
LN13	-1.96
LN14	-0.44
LN15	-6.96
Mean	-0.04
Stnd Dev	5.83

APPENDIX B

STATISTICS

Table 20. Description of the power details

Alpha (α)	Represents the significance level which is 0.05,
Sigma (σ)	Represents the standard error of the residual error in the model in this case it is RMSE (the square root of the mean square error)
Delta (δ)	Represents the raw effect size. In this case it is the square root of the sum of squares for the hypothesis divided by *n* is in the first box.
Power	Represents the power (the probability of a significant result) as a function of α, σ, δ, and *n*.
Least Significant Number	Represents the number of observations expected to achieve significance alpha given α, σ, and δ.

Table 21. Tip of nose pairwise comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
Non-High Angle Extraction	High Angle Extraction	0.970	-0.746	2.685	0.431
Non-High Angle Extraction	Non-High Angle Non-extraction	0.799	-0.736	2.333	0.502
High Angle Non-extraction	High Angle Extraction	0.765	-0.879	2.409	0.594
High Angle Non-extraction	Non-High Angle Non-extraction	0.594	-0.860	2.048	0.688
Non-High Angle Extraction	High Angle Non-extraction	0.205	-1.563	1.972	0.989
Non-High Angle Non-extraction	High Angle Extraction	0.171	-1.220	1.562	0.987

Table 22. Chin pairwise comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
Non-High Angle Extraction	High Angle Extraction	2.484	-2.056	7.024	0.460
High Angle Non-extraction	High Angle Extraction	2.058	-2.292	6.409	0.581
Non-High Angle Non-extraction	High Angle Extraction	1.759	-1.921	5.439	0.573
Non-High Angle Extraction	Non-High Angle Non-extraction	0.725	-3.336	4.786	0.962
Non-High Angle Extraction	High Angle Non-extraction	0.426	-4.251	5.103	0.995
High Angle Non-extraction	Non-High Angle Non-extraction	0.299	-3.549	4.147	0.997

Table 23. Right commissure comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Non-extraction	High Angle Extraction	4.804	1.397	8.210	0.0031*
High Angle Non-extraction	Non-High Angle Extraction	2.547	-1.115	6.209	0.255
Non-High Angle Non-extraction	High Angle Extraction	2.454	-0.428	5.335	0.118
High Angle Non-extraction	Non-High Angle Non-extraction	2.350	-0.663	5.363	0.171
Non-High Angle Extraction	High Angle Extraction	2.257	-1.298	5.812	0.330
Non-High Angle Non-extraction	Non-High Angle Extraction	0.197	-2.983	3.377	0.998

Table 24. Upper lip comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Non-extraction	High Angle Extraction	2.710	-0.494	5.913	0.121
High Angle Non-extraction	Non-High Angle Extraction	2.420	-1.023	5.864	0.246
High Angle Non-extraction	Non-High Angle Non-extraction	1.484	-1.349	4.317	0.497
Non-High Angle Non-extraction	High Angle Extraction	1.226	-1.484	3.936	0.616
Non-High Angle Non-extraction	Non-High Angle Extraction	0.937	-2.053	3.926	0.831
Non-High Angle Extraction	High Angle Extraction	0.289	-3.054	3.632	0.995

Table 25. Lower lip comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Non-extraction	High Angle Extraction	3.262	0.427	6.097	0.0191*
High Angle Non-extraction	Non-High Angle Non-extraction	1.818	-0.689	4.326	0.222
Non-High Angle Extraction	High Angle Extraction	1.768	-1.191	4.726	0.383
High Angle Non-extraction	Non-High Angle Extraction	1.494	-1.554	4.542	0.552
Non-High Angle Non-extraction	High Angle Extraction	1.444	-0.955	3.842	0.376
Non-High Angle Extraction	Non-High Angle Non-extraction	0.324	-2.322	2.970	0.987

Table 26. Left commissure comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Non-extraction	High Angle Extraction	3.532	-0.543	7.608	0.108
High Angle Non-extraction	Non-High Angle Non-extraction	2.204	-1.400	5.809	0.363
Non-High Angle Extraction	High Angle Extraction	2.017	-2.236	6.270	0.579
High Angle Non-extraction	Non-High Angle Extraction	1.515	-2.866	5.897	0.785
Non-High Angle Non-extraction	High Angle Extraction	1.328	-2.120	4.775	0.726
Non-High Angle Extraction	Non-High Angle Non-extraction	0.689	-3.115	4.493	0.961

Table 27. Right cheek comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Extraction	High Angle Non-extraction	1.468	-0.492	3.428	0.198
High Angle Extraction	Non-High Angle Extraction	0.785	-1.261	2.830	0.728
High Angle Extraction	Non-High Angle Non-extraction	0.777	-0.881	2.434	0.589
Non-High Angle Non-extraction	High Angle Non-extraction	0.692	-1.042	2.425	0.703
Non-High Angle Extraction	High Angle Non-extraction	0.684	-1.423	2.791	0.816
Non-High Angle Non-extraction	Non-High Angle Extraction	0.008	-1.821	1.837	1.000

Table 28. Left cheek comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
Non-High Angle Extraction	High Angle Non-extraction	1.566	-0.664	3.796	0.247
High Angle Extraction	High Angle Non-extraction	1.389	-0.685	3.464	0.285
Non-High Angle Non-extraction	High Angle Non-extraction	0.972	-0.863	2.806	0.488
Non-High Angle Extraction	Non-High Angle Non-extraction	0.594	-1.342	2.530	0.839
High Angle Extraction	Non-High Angle Non-extraction	0.418	-1.337	2.173	0.917
Non-High Angle Extraction	High Angle Extraction	0.176	-1.989	2.341	0.996

Table 29. Volume comparisons

Group	- Group	Mean Difference	Lower CL	Upper CL	p-Value
High Angle Non-extraction	High Angle Extraction	13.995	-1.467	29.457	0.087
Non-High Angle Extraction	High Angle Extraction	9.850	-6.285	25.984	0.364
Non-High Angle Non-extraction	High Angle Extraction	9.121	-3.958	22.200	0.253
High Angle Non-extraction	Non-High Angle Non-extraction	4.874	-8.801	18.549	0.770
High Angle Non-extraction	Non-High Angle Extraction	4.145	-12.476	20.766	0.906
Non-High Angle Extraction	Non-High Angle Non-extraction	0.729	-13.702	15.160	0.999

Table 30. Within group differences - commissures

Measure	*Difference*	*Lower 95% CI*	*Upper 95% CI*	*P-Value*
Non-High Angle Extraction	-0.52	-1.64	0.60	0.28
High Angle Extraction	-0.76	-2.84	1.32	0.42
High Angle Non-Extraction	0.51	-1.56	2.58	0.86
Non-High Angle Non-Extraction	0.36	-0.36	1.09	0.29

Table 31. Within group differences – cheeks

Measure	*Difference*	*Lower 95% CI*	*Upper 95% CI*	*P-Value*
Non-High Angle Extraction	0.35	-1.18	1.89	0.58
High Angle Extraction	-0.60	-1.55	0.33	0.17
High Angle Non-Extraction	-0.52	-1.24	0.18	0.12
Non-High Angle Non-Extraction	-0.24	-0.74	0.25	0.30

Table 32: Shapiro-Wilke's Test for Normality -- Group LE

Variable	Obs	W	V	z	Prob>z
Tip of Nose	6	0.85	1.84	0.989	0.161
Chin	6	0.66	4.19	2.822	0.002
Right Commissure	6	0.92	1.01	0.007	0.497
Upper Lip	6	0.79	2.66	1.714	0.043
Lower Lip	6	0.91	1.17	0.236	0.407
Left Commissure	6	0.96	0.45	-1.026	0.848
Right Cheek	6	0.77	2.88	1.891	0.029
Left Cheek	6	0.91	1.14	0.195	0.423
Volume	6	0.76	2.96	1.953	0.025

Table 33: Shapiro-Wilke's Test for Normality – Group HE

Variable	Obs	W	V	z	Prob>z
Tip of Nose	8	0.85	2.14	1.356	0.087
Chin	8	0.94	0.89	-0.194	0.577
Right Commissure	8	0.91	1.22	0.333	0.370
Upper Lip	8	0.58	5.89	3.755	0.000
Lower Lip	8	0.87	1.83	1.047	0.147
Left Commissure	8	0.98	0.34	-1.524	0.936
Right Cheek	8	0.93	0.94	-0.107	0.542
Left Cheek	8	0.95	0.63	-0.707	0.760
Volume	8	0.92	1.08	0.129	0.449

Table 34: Shapiro-Wilke's Test for Normality – Group HN

Variable	Obs	W	V	z	Prob>z
Tip of Nose	7	0.92	1.06	0.084	0.467
Chin	7	0.83	2.28	1.446	0.074
Right Commissure	7	0.92	1.09	0.136	0.446
Upper Lip	7	0.98	0.23	-1.880	0.970
Lower Lip	7	0.85	1.97	1.155	0.124
Left Commissure	7	0.76	3.15	2.140	0.016
Right Cheek	7	0.92	1.04	0.064	0.474
Left Cheek	7	0.83	2.26	1.429	0.077
Volume	7	0.95	0.69	-0.543	0.706

Table 35: Shapiro-Wilke's Test for Normality -- Group LN

Variable	Obs	W	V	z	Prob>z
Tip of Nose	15	0.86	2.66	1.935	0.027
Chin	15	0.89	2.18	1.539	0.062
Right Commissure	15	0.96	0.74	-0.601	0.726
Upper LIp	15	0.95	0.99	-0.027	0.511
Lower Lip	15	0.90	1.89	1.259	0.104
Left Commissure	15	0.96	0.71	-0.686	0.754
Right Cheek	15	0.94	1.13	0.245	0.403
Left Cheek	15	0.92	1.56	0.879	0.190
Volume	15	0.93	1.44	0.725	0.234

Table 36. Equal Variance Test - Levene

	F-Ratio	DF-Num	DF-Den	P-Value
Upper Lip	1.58	3	32	0.242
Lower Lip	2.77	3	32	0.088
Right Commissure	2.71	3	32	0.093
Left Commissure	1.05	3	32	0.425
Tip of Nose	1.53	3	32	0.442
Right Cheek	2.13	3	32	0.142
Left Cheek	2.10	3	32	0.145
Chin	0.77	3	32	0.536
Volume	2.48	3	32	0.113

Table 37. Parametric ANOVA tests

	$\mathbf{Num}_{df}$	$\mathbf{Den}_{df}$	F	P-Value
Upper Lip	3	32	2.043	0.127
Lower Lip	3	32	3.276	0.034
Right Commissure	3	32	4.880	0.006
Left Commissure	3	32	1.923	0.145
Tip of Nose	3	32	1.190	0.326
Right Cheek	3	32	1.386	0.264
Left Cheek	3	32	1.541	0.222
Chin	3	32	0.932	0.436
Volume	3	32	2.198	0.107

Table 38. Power Analysis

	Alpha	Sigma	Delta	Power	LSN
Upper Lip	0.05	2.284	0.942	0.474	50
Lower Lip	0.05	2.021	1.056	0.480	32
Right Commissure	0.05	2.429	1.550	0.869	23
Left Commissure	0.05	2.906	1.163	0.449	52
Tip of Nose	0.05	1.170	0.370	0.289	82
Right Cheek	0.05	1.397	0.475	0.332	71
Left Cheek	0.05	1.479	0.530	0.366	64
Chin	0.05	3.102	0.864	0.231	104
Volume	0.05	11.020	4.710	0.510	46

APPENDIX C

COLOR HISTOGRAMS

Figure 4. HE 1 histogram

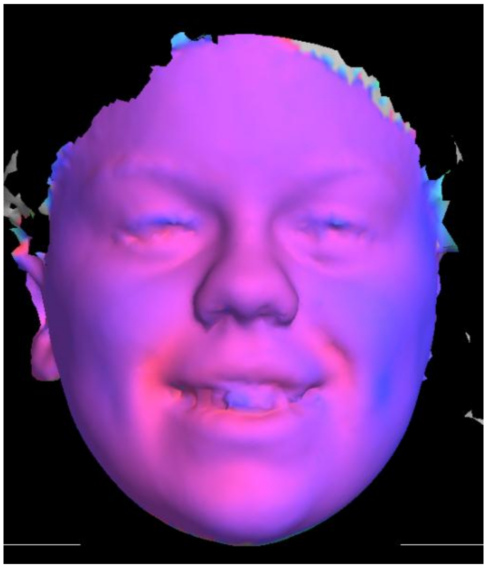


Figure 5. HE 2 histogram

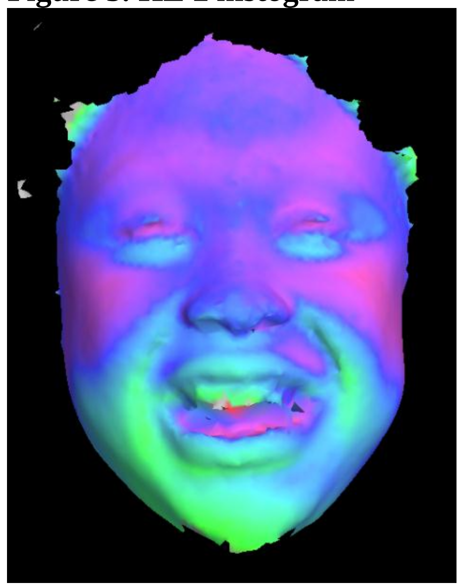


Figure 6. HE 3 histogram

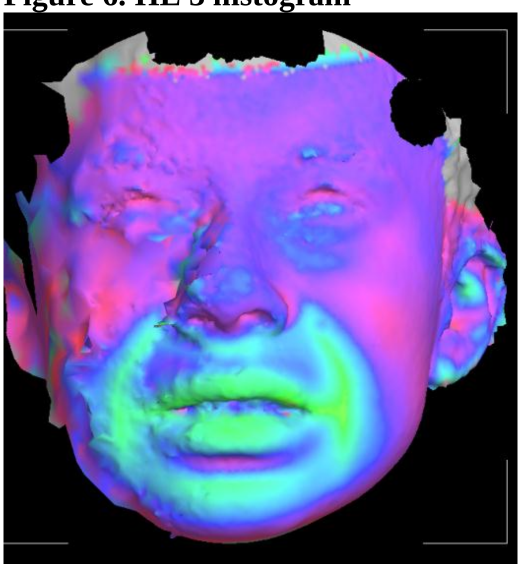


Figure 7. HE 4 histogram

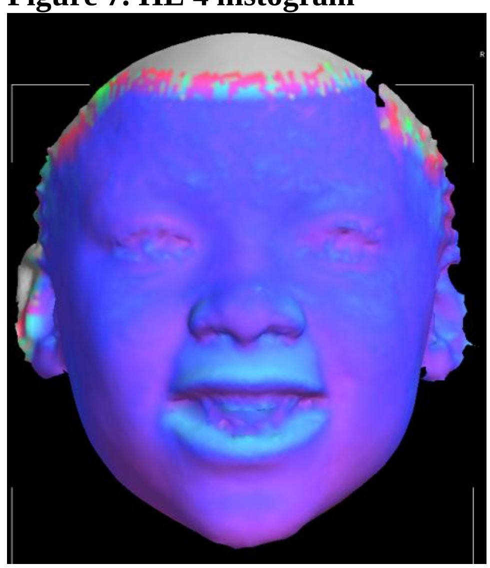


Figure 8. HE 5 histogram

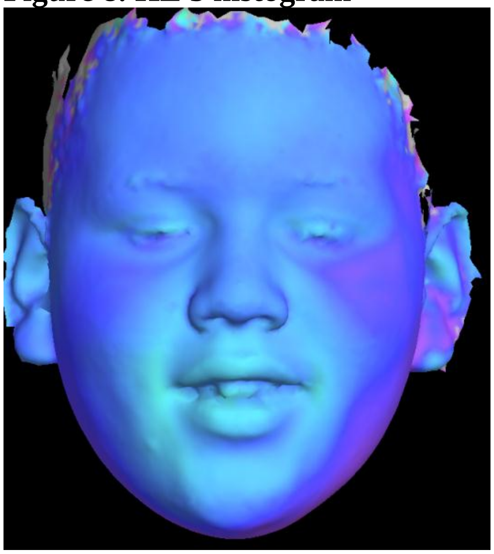


Figure 9. HE 6 histogram

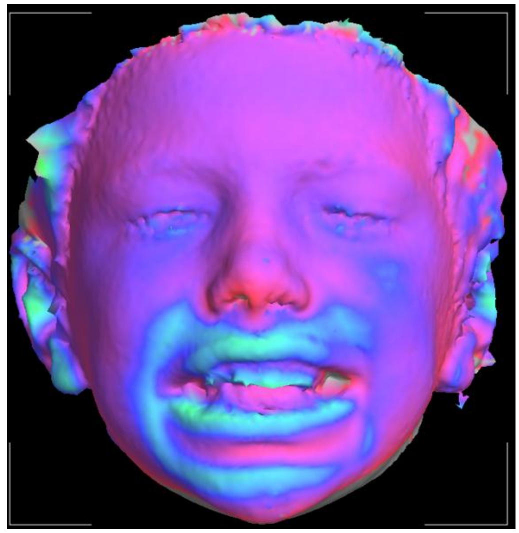


Figure 10. HE 7 histogram

Figure 11. HE 8 histogram

Figure 12. LE 1 histogram

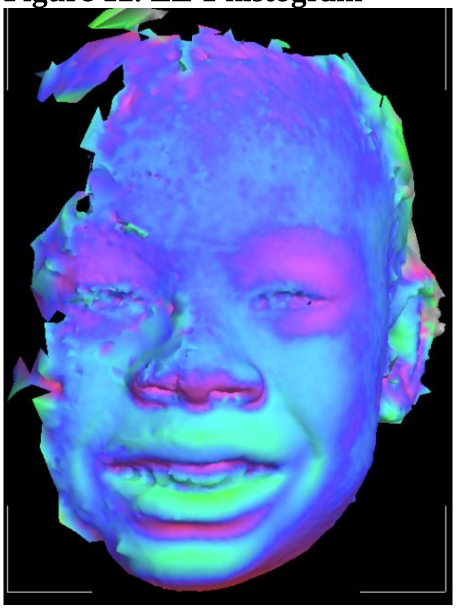


Figure 13. LE 2 histogram

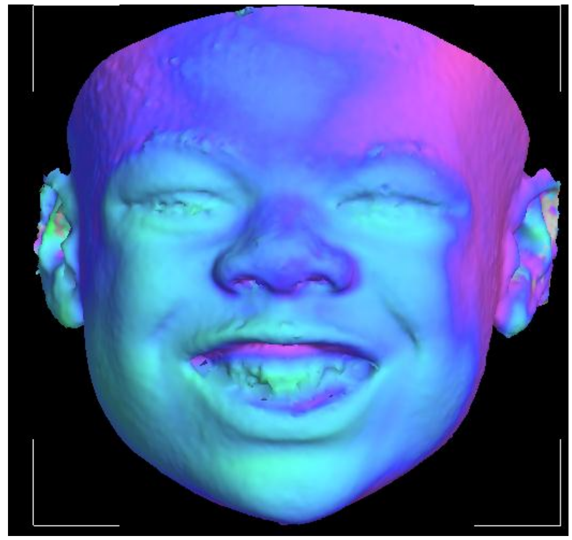


Figure 14. LE 3 histogram

Figure 15. LE 4 histogram

Figure 16. LE 5 histogram

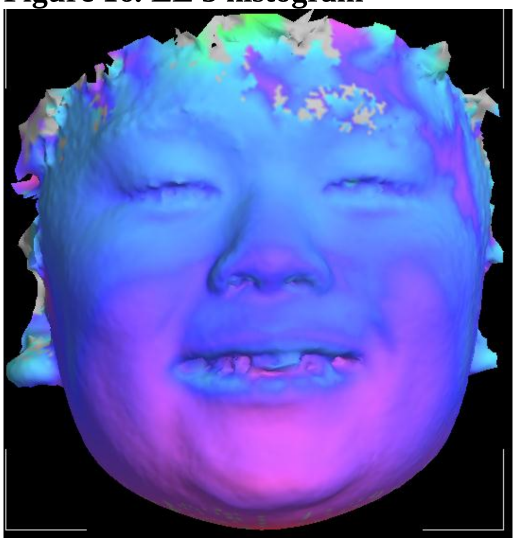


Figure 17. LE 6 histogram

Figure 18. HN1 histogram

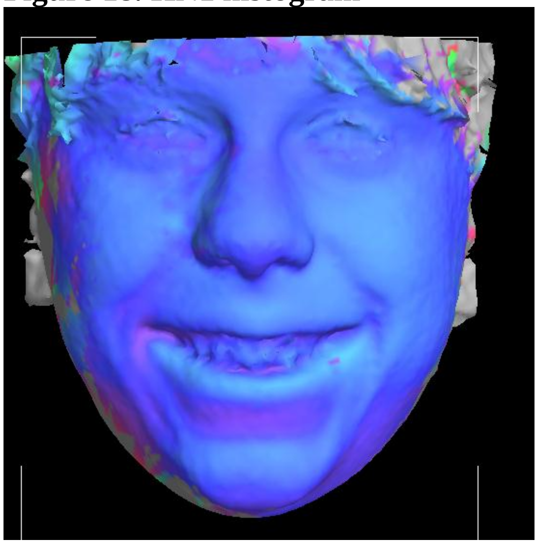


Figure 19. HN 2 histogram

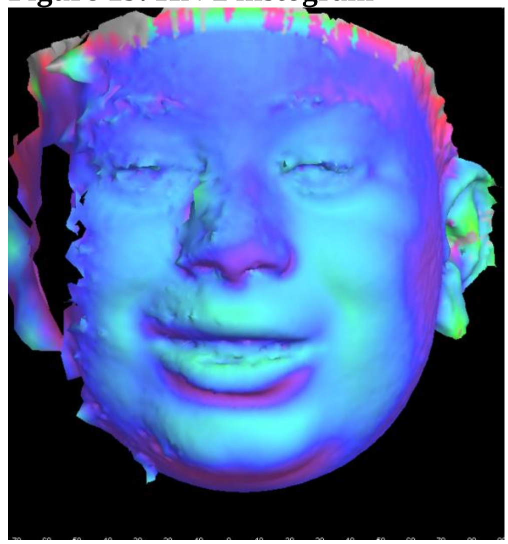


Figure 20. HN 3 histogram

Figure 21. HN 4 histogram

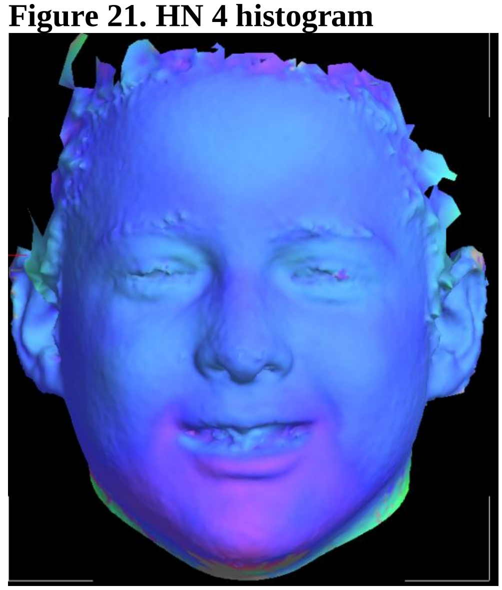


Figure 22. HN5 histogram

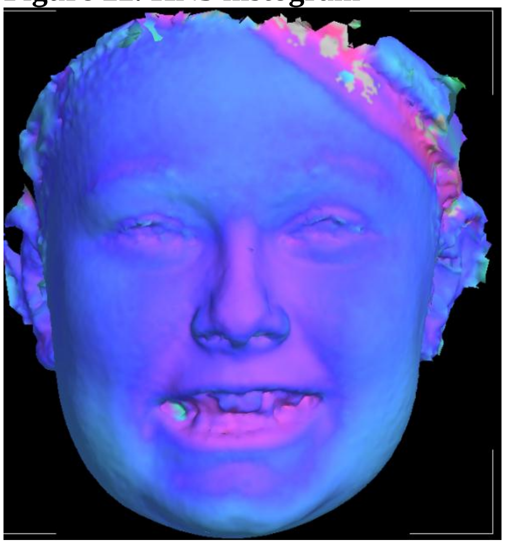


Figure 23. HN6 histogram

Figure 24. HN7 histogram

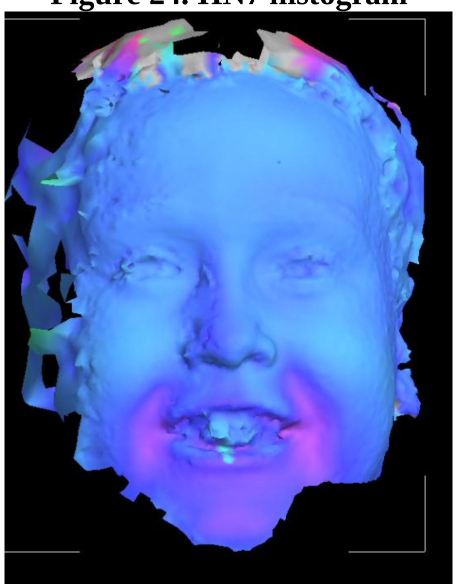


Figure 25. LN 1 histogram

Figure 26. LN 2 histogram

Figure 27. LN 3 histogram

Figure 28. LN 4 histogram

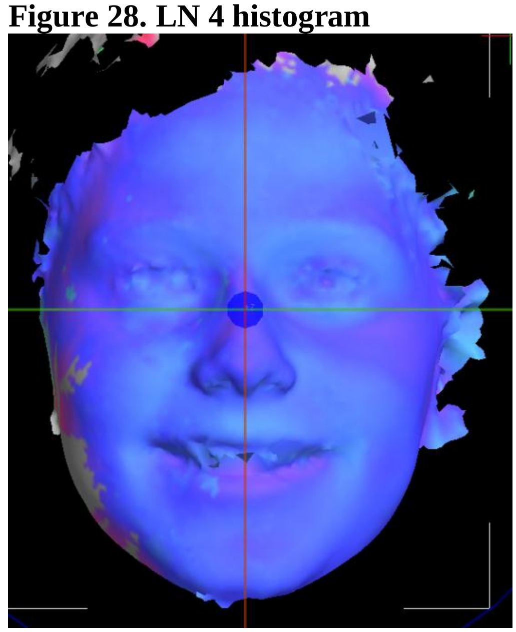


Figure 29. LN 5 histogram

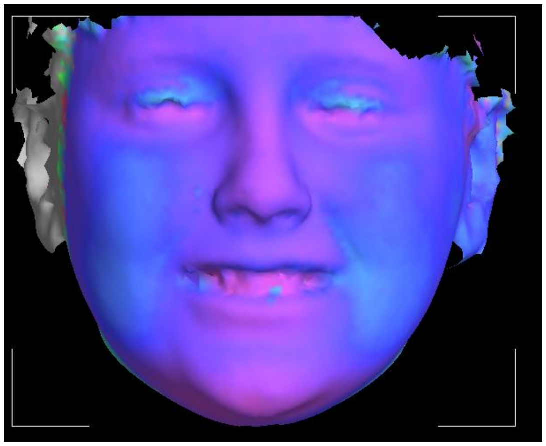


Figure 30. LN 6 histogram

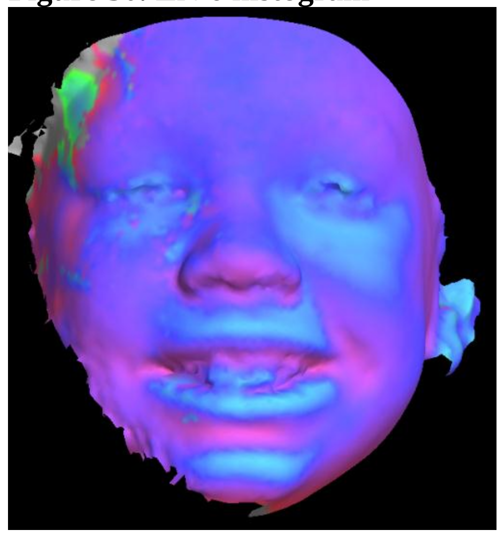


Figure 31. LN 7 histogram

Figure 32. LN 8 histogram

Figure 33. LN 9 histogram

Figure 34. LN 10 histogram

Figure 35. LN 11 histogram

Figure 36. LN 12 histogram

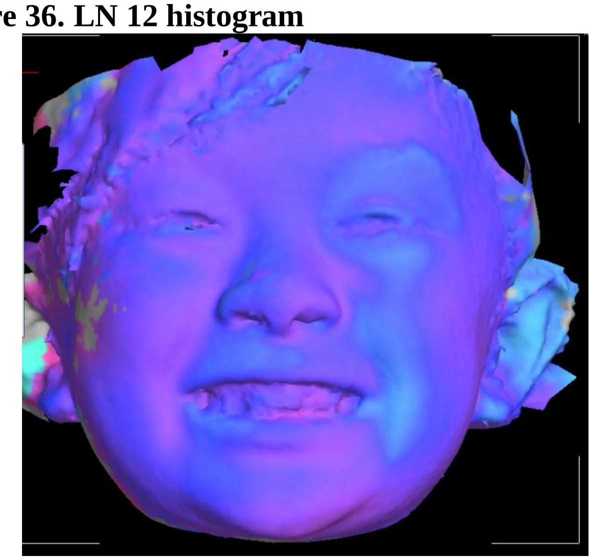


Figure 37. LN 13 histogram

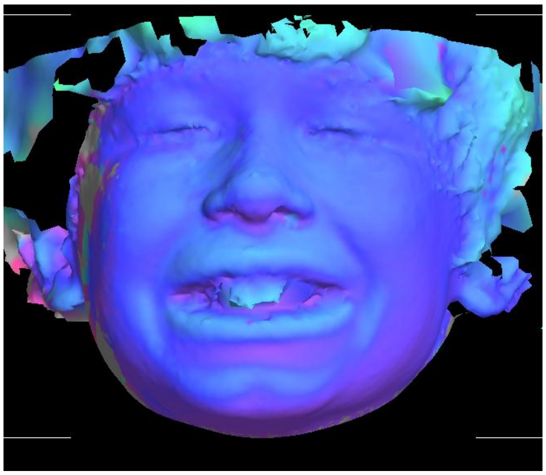
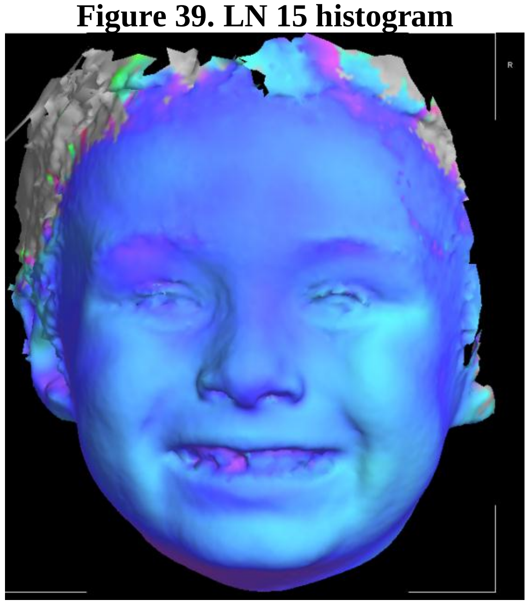


Figure 38. LN 14 histogram

Figure 39. LN 15 histogram



APPENDIX D

INDIVIDUAL QUALITATIVE RESULTS

Table 39. Group HE individual qualitative results

Subj.	Nose	Chin	Right commissure	Upper lip	Lower lip	Left commissure	Right cheek	Left cheek
HE1	++	+	+++	++	++	++	+	+
HE2	0	---	--	-	--	-	0	+
HE3	+	0	--	--	--	---	+++	++
HE4	0	0	0	-	-	0	0	0
HE5	0	0	-	-	-	-	0	0
HE6	+++	-	0	-	-	++	+	++
HE7	0	0	-	-	0	-	+	+
HE8	0	--	-	---	---	-	0	-

Table 40. Group LE individual qualitative results

Subj.	Nose	Chin	Right commissure	Upper lip	Lower lip	Left commissure	Right cheek	Left cheek
LE1	0	--	0	-	--	0	-	-
LE2	0	-	-	-	-	-	-	-
LE3	0	0	0	0	0	0	0	0
LE4	0	0	0	-	-	-	0	0
LE5	+	++	0	0	0	0	-	-
LE6	+	0	-	-	-	-	0	0

Table 41. Group HN individual qualitative results

Subj.	Nose	Chin	Right commissure	Upper lip	Lower lip	Left commissure	Right cheek	Left cheek
HN1	0	0	+	0	-	0	0	-
HN2	+	0	0	-	-	-	-	-
HN3	+	++	0	0	-	+	-	-
HN4	0	++	+	0	+	+	0	0
HN5	++	0	+	+	++	+	0	0
HN6	++	++	+	+	++	0	+	+
HN7	0	+	++	+	+	++	-	-

Table 42. Group LN individual qualitative results

Subj.	Nose	Chin	Right commissure	Upper lip	Lower lip	Left commissure	Right cheek	Left cheek
LN1	0	0	-	0	-	-	0	0
LN2	0	0	0	0	-	0	0	0
LN3	0	0	+	+	+	+	0	0
LN4	0	0	0	0	+	0	0	0
LN5	++	++	+	+	++	+	0	0
LN6	+++	+	+++	0	0	+++	+	0
LN7	0	0	-	-	-	-	0	0
LN8	0	0	0	0	0	0	0	0
LN9	+	++	0	+	++	0	+	+
LN10	+	0	0	0	0	+	+	+
LN11	+	++	0	0	0	0	0	0
LN12	+	+	+	+	+	+	+	0
LN13	0	0	0	0	0	0	0	0
LN14	0	0	0	0	0	0	0	0
LN15	0	0	0	0	0	0	-	-