Three-Dimensional Shape of Facial Attractiveness in Patients with Sagittal Skeletal Discrepancy

by

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ABSTRACT

Many patients with sagittal skeletal discrepancy (SSD) express dissatisfaction with their facial esthetics. Studies have shown that males and females possess distinct recognizable facial features that need to be considered when addressing these concerns. We sought to identify the 3D morphological shape correlates of facial attractiveness (FATT) and sexual dimorphism (SD) using CBCT scans of subjects with SSD. Forty anonymized CBCT images of adult subjects with varying severity of SSD were evaluated for FATT and masculinity/femininity (M/F) by 100 laypeople using Visual Analog Scales (VAS). Using Geometric Morphometric (GM) analysis, we found that more anterior and inferior shape displacement of the chin was significantly associated with increases in FATT (R^2=0.46, b=0,0015, P= 0.049). Prominent cheeks and posterior displacement of the tip of the nose were associated with a more feminine facial appearance (R^2=0.62, b=0.0013, P=0.192). Our results provide guidance in the treatment planning of subjects with SSD, taking sex into consideration.

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LIST OF ABBREVIATIONS

FATT	Facial Attractiveness
SSD	Sagittal Skeletal Dysplasia
SD	Sexual Dimorphism
M/F	Masculinity and Femininity
CBCT	Cone-Beam Computed Tomography
GM	Geometric Morphometrics
LFH	Lower Face Height
UFH	Upper Face Height
NHP	Natural Head Position
CASS	Computer Aided Surgical Simulation

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CHAPTER 1
LITERATURE REVIEW

1

1.1 Introduction

Beauty is defined as a combination of qualities, such as shape, color, or form, that pleases the senses of the mind.[1] Facial beauty especially is an important and valued aspect of human life.[1] Individuals possessing attractive faces have been shown to lead favorable lives and pay lower bail [2] and are more likely to be hired and promoted for jobs.[3,4] Perception of beauty, however, varies dramatically as it is influenced by the observer's own judgement, ideas, or feelings.[5] As a result, beauty in general and facial beauty in particular is difficult to measure or evaluate.

In spite of the subjectivity of the perception of facial beauty, universal standards exist.[6] The creation of an esthetic or "harmonious" face requires a condition where the skeletal bases of the maxilla and mandible are of the correct size relative to each other and the teeth at rest are in correct relationship in all three planes of space.[7,8] Dentofacial relations that have discrepancies between the skeletal bases are known as sagittal skeletal disharmony (SSD). Interestingly, the patient's chief complaint will often be related to the facial consequences of the SSD, and not necessarily to the dental relationship.[9,10] One of the principal facial features believed to make patients with SSD less attractive is the retrusive position of the chin leading to a convex profile.[11] However, compensations (dental or soft tissues) in these patients may act as a camouflage to provide a more balanced profile and facial esthetics.[12]

Another important aspect of facial beauty is sexual dimorphism (SD).[13] Indeed, studies have shown that males and females possess distinct recognizable facial features. For example, females have fuller and thicker lips, a small nose and chin, narrow jaws, while males tend to have bigger noses, large jaws, strong chin, small eyes, and thin lips.[14] In profile view, the chin provides harmony and character to the face. A slightly retruded chin was considered a female beauty ideal in the first half of the last century.[15] Nowadays, a straight profile with a rather dominant chin has been deemed aesthetic.[15] Thus, a strong chin or prominent jawline is considered to be aesthetically pleasing, especially in males.[11]

Various techniques have been used in the past to evaluate facial aesthetics, such as silhouettes, photographs, line drawings and cephalometric analysis.[5,16-18] The main drawback of these methods is that it provides a two-dimensional (2D) view of a three-dimensional (3D) face. Considering the advancements made in digital imaging, it has since become possible to use 3D imaging to help replicate the anatomic and physiological reality of the bone, soft tissue, and teeth.[19] Cone beam computed tomography (CBCT) is an imaging technique that can acquire and relate soft tissues and underlying hard tissues of the face in a single run.[19-22]

Patients with SSD comprise a major group of patients in an orthodontic office with many of them expressing dissatisfaction with their facial esthetics. The facial characteristics of patients with SSD at the 3D level have not been clearly defined in terms of the morphological shape or the impact of sex differences that contribute to attractiveness versus non-attractiveness. In an era where patients are increasingly requesting esthetic improvements and gender identity change, a better knowledge of such attributes will guide orthodontists in the treatment planning of patients with SSD. It is therefore the focus of our study to define which morphological features can render a patient with SSD more or less attractive, taking SD in consideration.

This thesis project seeks to understand and define the 3D characteristics of FATT and sexual dimorphism using CBCT studies of patient with SSD. In the next chapter, the definition of FATT, imaging techniques and geometric morphometrics will be reviewed.

1.2 Facial Esthetics

1.2.1 Facial Beauty

Beauty has a purpose in nature and can be correlated with health, strength, and youthfulness in the animal kingdom.[23] Insect pollinators, for example, will be attracted to the most beautiful or fragrant flowers to assure their survival. In humans, attractive children and adults are deemed nicer, better, healthier, and more intelligent than their plain or unattractive peers.[24] Even though we know the importance of beauty in life, it is difficult to clearly and accurately define beauty. A longstanding debate revolves around the question of the subjectivity-objectivity of beauty. Indeed, perception of beauty varies dramatically as it is influenced by the observer’s own judgement, ideas, or feelings.[5,25] As a result, beauty in general and facial beauty in particular is difficult to measure or evaluate.

In spite of the subjectivity of the perception of facial beauty, universal standards exist.[6] There are a variety of qualities and characteristics of a human face, which may be responsible for it being perceived as beautiful. These include 'ideal' proportions, bilateral symmetry, averageness, youthfulness and sexual dimorphism. Hereditary factors and cultural influences also play an important part.[1] Any or all may have an effect on the human perception of beauty, but none fully explains why one face is seen as beautiful and another as unattractive.

1.3 History of Facial Beauty

Guidelines used by clinicians today to measure 'ideal' facial measurements and proportional relationships are based on those initially described in art and sculpture in history.[13,26] However, these guidelines have evolved from the original canons and are now based on modern anthropometric and cephalometric studies of population averages and ranges of normal variation.

Ancient Egyptians (2600 to 2000BC) had a great interest in art and beauty and tried to find harmonious proportions and canons to immortalize the beauty of their kings and queens (Figure 1). To guide them in the proportional construction of the head, Egyptians used lines representing the crown of the head, the hairline, and the junction of the neck and shoulders.[13,26] The Greeks had the desire to obtain naturalism in art and sculpture and abandoned the rigid geometric forms developed by the Egyptians. They established intricate formulas and canons for constructing ideally proportioned human and godly representations.[13,26] The classic Greek face is oval, slightly tapering down the chin and has the same canons for males and females, best represented by the head of Aphrodite (Figure 2).[26] In profile view, the lower face is usually orthognathic in profile and displays some retrusion around the lips and a prominent chin with a sharp mentolabial sulcus.[13,26]

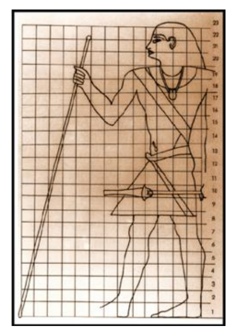


Figure 1. Proportional construction and illustration of the human body by Egyptians. Reproduced with permission from John Wiley and Sons.

During the Renaissance, Leonardo da Vinci (1452-1519) and his contemporaries typified the new integration of art and science using mathematical explanations of nature to portray the human facial form.[13,26] The most popular method of measurement at Renaissance was the "golden section" or "divine proportions" developed by Leonardo Fibonaci.[18,24] The concept was to apply the number 1.618 (Phi,ϕ) or its reciprocal 0.618 on facial and bodily proportions.[26] For centuries, it was considered the perfect ratio for beauty.[6,23,27]

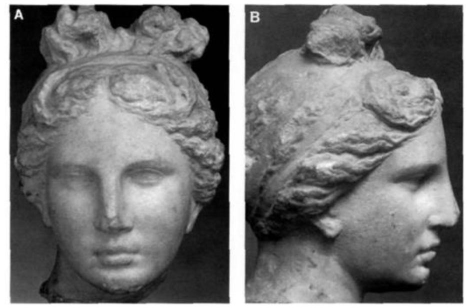


Figure 2. Head of Aphrodite. Reproduced with permission from Wiley and Sons.

In the twentieth century, the development of modern craniofacial anthropometry (i.e., the scientific study of the measurements and proportions of the human body) and orthodontic cephalometry led to better understanding of facial proportions and relationships. The facial standards of beauty, however, were still compared to the classical Greek canons (Figure 2).[28] However, in 1921, Calvin S. Case[29], an orthodontist from Chicago, proposed that "standard of beauty should not be confined to a fixed idea of facial outlines of classical art, but it should be one which may at times be adjusted to the different types of physiognomies that present for treatment".[26] Case went so far as to make plaster facial casts of his patients to show the facial changes reflected in his treatment. Nowadays, the Greek model of beauty has almost vanished from social media.[26] In 1952, Peck studied 52 attractive subjects (models, actress, beauty contest winners etc.).[30] Photographs and sagittal cephalograms were measured and analyzed and the results showed that the general public preferred a more full and protrusive dentofacial pattern rather than customary cephalometric standards.[30] In the 1960's, Dr. Leslie Farkas, a pioneer in anthropometry, compiled enormous databases of norms.[31] His work will be described in later sections of this chapter.

1.3.1.1 Golden Proportions

Ricketts was one of the first orthodontist to apply the golden proportions or "golden sectioning" to multiple proportions of the face such as nose width versus mouth width, tooth height versus tooth width. More recently, Marquardt[32] developed a mask based on the "divine proportion" to evaluate facial beauty; if the face fits the mask, it will be esthetically pleasing (Figure 3).[6] Hence, the faces of professional models have not been found to always fit the golden proportion, and a study looking at the esthetic improvement of patients undergoing orthognathic surgery found that while most subjects were considered more esthetic after treatment than before, the proportions were equally likely to move away from or towards the golden proportion.[33] Although the golden ratio has been used to describe canons of facial esthetics for years, contemporary authors have claimed that it does not account for ethnical and sex differences[34]; to this day, this method remains unproven scientifically.

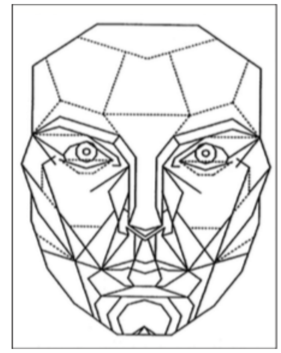


Figure 3. Frontal beauty mask based on divine proportions. Reproduced with permission from

1.3.2 Beauty and Culture

The human perception of facial beauty may have its foundation in our heredity, environment or perhaps both. Infants as young as three months of age have the ability to distinguish between attractive and unattractive faces, showing signs of preference for the former.[35,36] Indeed, adults as well as children tend to look longer at faces judged as attractive.[37,38,39] Throughout history and the world, there have been unique beauty standards for certain cultures or ethnic groups. For example, in ancient Egypt men found the bare female head appealing, while the "goitre neck" was found to be attractive in France around the 1800's.[40] Nevertheless, Perrett et al.[41] found that both Caucasian and Japanese men and women ranked female faces as most attractive when youthful facial features, such as large eyes, high cheekbones and a narrow jaw, were evident. Esthetic judgements therefore seemed to be similar across different cultural backgrounds. A meta-analysis undertaken by Langlois et al. also confirms that there is cross-cultural agreement regarding facial attractiveness.[36]

1.3.3 Beauty and Psychological Wellbeing

Facial beauty is an important and valued aspect of human life.[1] Individuals possessing attractive faces have been shown to lead favorable lives and pay lower bail.[2,3,4] Attractive children tend to be perceived more positively by their parents,[35] and by teachers who perceive more attractive children as being more intelligent.[42] Furthermore, in professional life, less attractive adults are perceived as having fewer qualifications and less potential for employment success.[43] Physical attractiveness is an important factor affecting social relationships and a compromised facial appearance is associated with a greater risk of developing psychological problems.[37,44]

A person's own perception of their facial appearance is of great importance. However, the psychological distress caused by a facial deformity is not proportional to its severity. Research indicate that facial deformities of a mild to moderate nature may cause greater psychological distress on patients than severe facial deformities.[45] This could be explained by the fact that other people's reactions towards milder deformities are more unpredictable whereas more severe deformities tend to evoke more consistent reactions, allowing the patient to develop better coping strategies.[1] The variability in people's reactions to milder facial deformities also results in considerable patient distress.[17] It is important to note that the majority of patients seeking orthodontic treatment or orthognathic surgery fit into the mild/moderate category in terms of facial deformity, as opposed to craniofacial malformation syndromes or severe facial trauma/disease.[46] Generally, women are more likely to seek treatment and experience more impairment related to malocclusion than men.[47] It has been shown that men are less concerned about self-perceived dentofacial appearance and report a more favorable overall body image than women.[47] The rationale underlying treatment recommendations based on esthetic impairment comes from the belief that compromised appearance will affect self-esteem, which in turn can lead to poor social adjustment and affective disorder.[48]

1.3.4 Anxiety, Depression and Perception of Beauty

Anxiety disorders are the most prevalent psychiatric disorders and they are highly associated with depressive disorders.[49] Stress, depression, and anxiety are emotional states that affect our mental and physical health. Socially anxious individuals are often overly self-conscious of their appearance while patients suffering of depression have a body image dissatisfaction with a particular focus on the face.[50,51] Similarly, judgement of attractiveness can be affected by the rater's own level of attractiveness [52], depression [53-55] and anxiety.[55,56] Depression is often characterized by a negative prejudice in perception of facial beauty[57,58] and anxiety will often lead to exaggerated and oversensitive negative evaluation of facial attractiveness and emotions.[50]

To determine an individuals' level of anxiety, the adult version of the State-Trait Anxiety Inventory (STAI)[59] forms Y1 and Y2 are used, among other questionnaires.[49] It is a self-report questionnaire which includes 20 questions evaluating trait anxiety and 20 questions evaluating state anxiety. Each question is scored on a 4-point scale. State anxiety is described as being a current, temporary feeling of anxiety whereas trait anxiety refers to a generalized feeling of anxiety as well as proneness to anxiety.[59]

1.4 Facial Attractiveness

Attractiveness is a perception of beauty related to cognitive processes and cultural preferences.[23] The first "study" in attractiveness was done in 1753 by the artist William Hogarth.[13] He drew the image of a woman's corset, and then proceeded to create variations of the same image while altering a certain aspect of the corset in each image. He subsequently invited members of the public to choose their favorite image. This experiment led to many other studies of attractiveness where laypeople were asked to choose the most attractive face or feature of a face. Following these studies, the four main cues that have been proposed to influence facial attractiveness are symmetry, averageness, youthfulness/neoteny, and sexual dimorphism.[24] These characteristics will be reviewed in this section.

1.4.1 Facial Symmetry

An attractive face possesses symmetry which refers to the extent that one half of an image is the same as the other half.[30] Although a small degree of bilateral facial asymmetry exists in all normal individuals, an obvious asymmetry or perfect bilateral symmetry is considered less attractive.[1,23,60,61] Importance of symmetry in ratings of facial attractiveness has been studied using computer constructed left-left /right-right symmetric faces (chimeric faces). In these studies, the assessors rated the original faces as more attractive than the perfectly symmetrical images (Figure 4) and the perfectly symmetric composite photographs decreased attractiveness scores.[62,63]

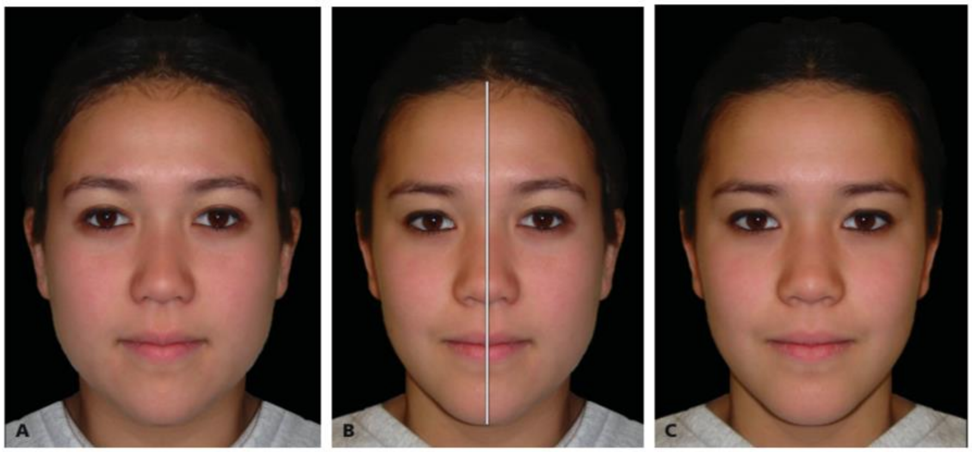


Figure 4. (A) Composite image of mirrored left facial hemisphere. (B) Original true image. (C) Constructed composite image of mirrored right facial hemisphere. Reproduced with permission from Wiley and Sons.

From the frontal view, most asymmetries show less than a 3% right-left difference[30] and are mostly located in the midface and lower face.[64] The threshold at which facial discrepancies become severe enough is when it is recognized simply by clinical observation of soft-tissue.[30] Faces that are either "too symmetric" or "too asymmetric" are perceived as unattractive. The acceptable range for how attractiveness is judged in faces must lie somewhere within the continuum, but the borders of the range are as yet unknown.[62,64] Symmetry can be observed by dividing the face in mesio-distal sagittal fifths.[65,66] These sagittal fifths will be described in more detail in future section of this review**.** Overall, symmetry is an important factor in facial attractiveness, but 'averageness' appears to be more important.[67]

1.4.2 Averageness

Averageness relates to how closely a face resembles the average population face.[23,68] Studies in the late 1800s by Sir Francis Galton (1822–1911), cousin of Charles Darwin, accidentally found evidence to support what came to be known as the averageness hypothesis of facial beauty. He created composite faces by overlaying multiple images of prisoners and criminals and produced composite portraits that were more attractive than any of the individual faces (Figure 5).[69]

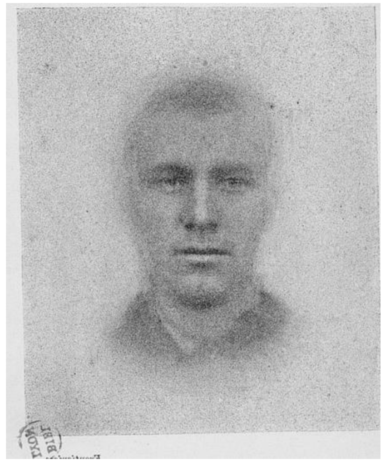


Figure 5. Facial composite of overlaying prisoners faces by Sir Francis Galton. Reproduced with permission from Wiley and Sons.

Contemporary studies have shown that faces or composites created from photographic superimposing techniques to combine facial images are judged more attractive than the constituent faces.[5,24,70-72] Langlois and Roggman observed that the more components were incorporated into a composite, the higher the rating.[71] For example, composites produced from 32 individuals scored higher attractiveness ratings than those produced from eight (Figure 6).[71]

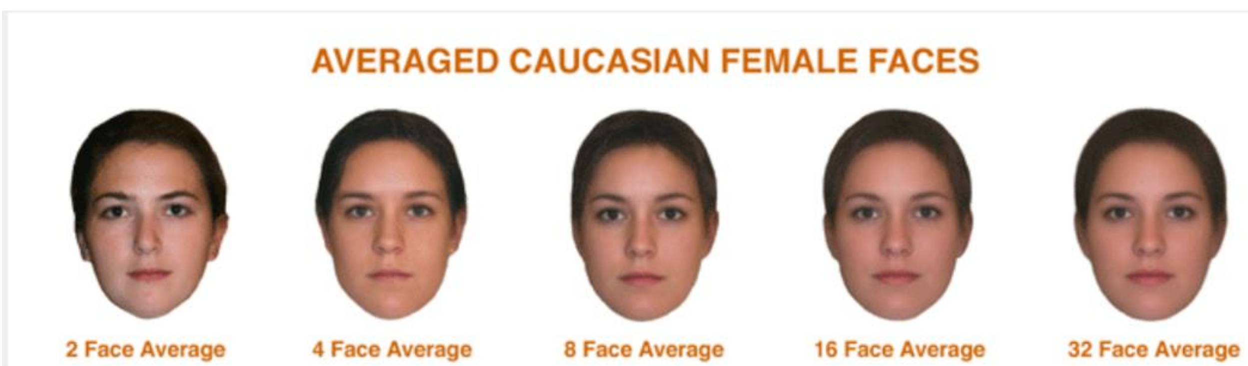


Figure 6. Average Caucasian Female Faces (Langlois et al, 1990). The average of the 32 faces was found to be the most attractive. Reproduced with permission from SAGE.

Rubenstein et al.[72] concurred that no matter how symmetrical a face, averageness is the only characteristic discovered to date which is both necessary and sufficient to ensure facial attractiveness. Without a facial configuration close to the average of the population, a face will not be attractive.[23,24,68] Attractive composite faces could be made more attractive by exaggerating the shape differences from the sample mean, implicating that an average face shape is attractive but may not be optimally attractive.[41] Langlois and Roggman's data did show that there were a few exceptionally attractive individuals, who were more attractive than the composites.[70,71] Therefore, this theory of 'averageness' is not necessarily exclusive and there seems to be other features such as youthfulness or sexual dimorphism that appear to be involved in facial beauty.[5]

1.4.3 Youthfulness and Facial Neoteny

The term neoteny refers to the retention of juvenile or child-like facial features in the adult. Many studies have confirmed that youthful faces are found to be more attractive than older faces.[23,24] Indeed, adult female faces retain more neonate features than male faces and gender maturity cues that enhance male attractiveness and dominance may reduce female attractiveness.[24] In children, the lower part of the head is smaller than in adults and the facial features (nose, eyes, lips) are further away from the top of the head; this makes them appear bigger than normal.[14] As we grow, these facial structures stay nearly the same dimensions, but the distance between them changes, making them look smaller in the adult face.[73]

In adolescence, there is more transformation in a male's face - the jaw and superciliary arches become more substantial, resulting in a mature and dominant face.[74,75] Since these changes do not occur as much in females, the feminine face usually retains youthful features.[14] Some example of childlike features are: high forehead, round face, large round eyes, bluish sclera, high eyebrows, thick red lips, short wide concave nose, wide cheeks, short ears, and light soft skin.[74,75] Studies consistently show that facial attractiveness in females is positively correlated with the measured baby-likeness of the facial proportions.[23,31,41,74]

1.4.4 Sexual Dimorphism

Sexual dimorphism is the condition where the two sexes of the same species exhibit different characteristics beyond the differences in their sexual organs (summarized in Table 1).[5,13,76,77] Male and female faces diverge at puberty.[67] In males, testosterone stimulates the growth of the jaws, cheekbones, brow ridges and facial hair. In females, growth of these regions is inhibited by estrogen but fat deposition through the body occurs increasing lip thickness and protrusion.[13,23,77] Women with higher circulating estrogen have more feminine faces with reduced angularity, while men with high testosterone have more masculine faces with increased angularity (Figure 7).

In 1985, Keating compared mature traits (thick brows, thin lips, prominent square jaw and wide face) and immature traits (thin brows, large eyes, thick lips, round jaw) on males and females facial composites.[75] Female raters selected men's faces that had 'dominant' or 'mature' features such as relatively large jaws, strong chin, prominent malar, small eyes, thick eyebrows and thin lips. The opposite 'non-dominant' features were selected by males assessing females, preferring mainly big eyes, short nose, small chin, thick lips and narrow jaw, thin eyebrows, and wide-set eyes. Female's preference for more masculine features increases during the ovulation cycle.[23,78] Evolutionarily speaking, dominant males were more successful in attracting mates and forming partnerships with other males while females would acquire access to resources indirectly through the social manipulation of dominant males.[75] Therefore, immature and juvenile characteristics generally elicit this caretaking response towards females with youthful features.[74,75] However, besides having many baby-like traits, an attractive woman should also possess some adult traits such as pronounced cheekbones and a narrow chin.[5,14,75] In addition, hyper-feminine faces tend to be even more attractive than a typical female face and is preferred to averageness. Male faces that are near the masculine average (moderate level of masculinity) are found to be more attractive than hyper-masculinized faces. Masculinity in male is attractive, but to a lesser extent that femininity is to female.[5,76,77] In both males and females, facial attractiveness is correlated to averageness and maturity while symmetry is often found to be a relatively weak determinant.[68,77]

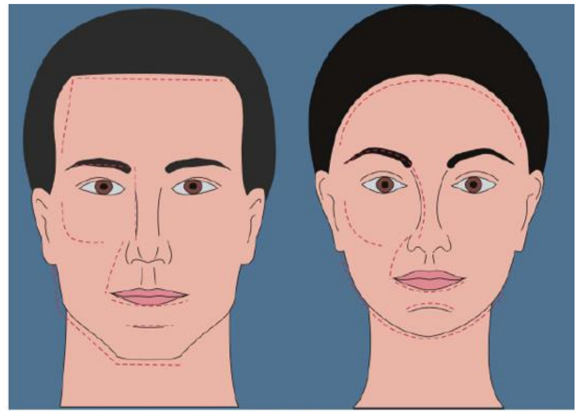


Figure 7. Facial Contour lines in men and women. Reproduced with permission from Wiley and Sons.

Table 1. Morphological Differences in Male and Female Faces [5,13,76,77]

	Females	Males
Body Size	Smaller	Larger

Shape of Face	• Oval shape
	• Smaller Lower Face Height (LFH)
		• Square shape
		• LFH is usually greater
		  ○ Increased lip height
		  ○ Increased chin height

Cranium	Thinner bone	Thicker bone and pronounced muscle insertion
Hairline	Rounded hairline	"M" shape
Forehead	Usually more vertical	Slopes posteriorly
Brow Ridge	• Smaller frontal sinus • Superciliary arches soft and roundly shapes	• Larger frontal sinus • Superciliary arches more pronounced • Superior margin of the orbit is more angular and squared shaped
Eyes	• Big eyes	• Horizontally straight • Positioned inferior to the orbital rim
Nose	• Small • Concave morphology on the dorsum	• Large and pronounced nose
Cheekbones	• Pronounced cheekbones • Rounded and thick cheeks	• More prominent cheekbones • Thin cheeks
Lip Morphology	• Greater vermilion exposure • Protrusive thick lips	• Thin lips • Wide mouth
Mandible	• Jaw line has a gentle curve from the ear to the chin • Narrow jaws	• Larger with broader bigonial width • Pronounced gonial angle • Square jaws
Chin	• Rounded • Narrow • Small	• Square shape • Broader • More pronounced (greater prominence of the mandibular symphysis)

1.5 Facial Analysis

Before the advent of cephalometric radiography and CBCT, dentists and orthodontists often used anthropometric measurements (i.e., measurements made directly during the clinical examination) to help establish facial proportions. Farkas's modern studies of Canadians of northern European origin provided the data for normal facial proportions.[31,79,80] This method was replaced by cephalometric analysis for many years but the recent emphasis on soft tissue proportions in orthodontics has brought soft tissue evaluation back into prominence.[23,81]

1.6 Frontal View Analysis

1.6.1 Vertical Proportions

One of the most important determinants of facial attractiveness are the facial proportions, which can be measured by fitting horizontal or vertical reference lines on the face. The vertical proportions of the face can be examined using cranio-caudal thirds as described in Table 2 and illustrated in Figure 8.[17,65] In attractive faces, these thirds are somewhat proportionate and equal to each other.[13,17,48] However, they may vary by ethnicity and gender. For example, in white individuals, the middle third of the face tends to be shorter than the upper and lower thirds.[65] In females, the lower facial third or LFH (lower face height) is equal to the middle facial third; in males, however, the LFH is longer due to a greater lower lip/chin height.[82]

Table 2. Description of Vertical Thirds

Upper Facial Third:	***Trichion (Tr) (Hairline) to Glabella (G')***
Middle Facial Third:	***Glabella (G') to Subnasale (Sn)***
Lower Facial Third:	***Subnasale to Soft tissue Menton (Me')***

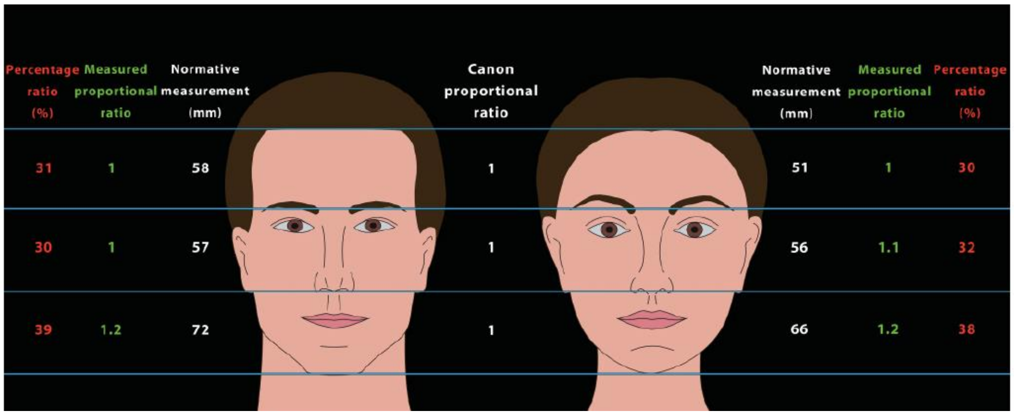


Figure 8. The Facial Trisection canon compared with proportional ratios derived from modern anthropometric measurements. Total face height is in general slightly more increased in males than females. However, the proportions are relatively the same. Reproduced with permission from Wiley and Sons.

1.6.2 Lower Facial Height

The lower third of the face, i.e. the lower facial height (LFH), can itself be divided into thirds (Figure 8) as described in Table 3:

Table 3. Lower Face Height Proportions

Upper Lip (1/3):	***Subnasale (Sn) to Stomion (St)***
Lower Lip (1/3):	***Stomion (St) to Mentolabial Sulcus***
Chin (1/3):	***Mentolabial Sulcus to Menton (Me')***

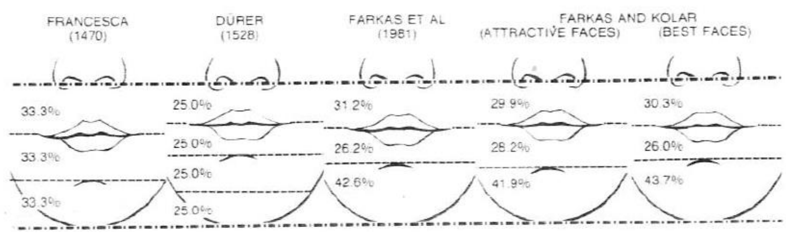


Figure 9. Variation in lower face height proportions. Most recently, a 30% to 70% ratio of this upper third to lower two-third proportion has been found in attractive subjects (image on the far right). Reproduced with permission from Elsevier.

Throughout the years, different ratios have been found for the lower facial thirds (Figure 9). More recently, a 30% to 70% ratio of this upper third to lower two-third proportion has been found in attractive subjects.[27,79,80] As we can see from Figure 9, there is variation in the proportional canons and individual variability in the results of modern studies; these proportions should therefore only be used as *guidelines* when evaluating patients clinically. The most attractive lower face proportion (Subnasale to Menton) has been found to be 55% of total anterior face height (measured from Nasion to Menton); this corresponds to a UFH:LFH ratio of 50:50 if the face height is measured from glabella.[83] Furthermore, images with reduced lower face proportion were considered more attractive than corresponding images with an increased lower face proportion.[83] Knowledge of vertical facial proportions is important in planning dentofacial surgery. Disproportion of the facial vertical thirds may be a result of many dental and skeletal factors, and these measurements can help us define the contributing factors to vertical skeletal discrepancies.

1.6.3 Profile Esthetics

The facial profile of an individual is a crucial element in describing the beauty of a face, especially for orthodontists. The profile helps determine how the chin and the middle portion of the face relate to each other and is assessed by placing the patient in a natural head position (NHP).[84-86] The NHP can be achieved with the patient either sitting upright or standing and looking at the horizon, a distant object or their own eyes in a mirror.[84-86] The contour of the facial profile may be described as convex, straight or concave.[12]

To assess facial profile, a line (UFH) dropped from soft tissue glabella (G') to subnasale (Sn) is compared with a second line (LFH) extending from subnasale (Sn) to soft tissue pogonion (Pog'). In a straight or orthognathic profile, these lines are coincident and nearly form a straight line,[17,87] whereas in convex or concave profiles, the second line (LFH) is oriented towards or away from the chin, respectively (Figure 10).[13]

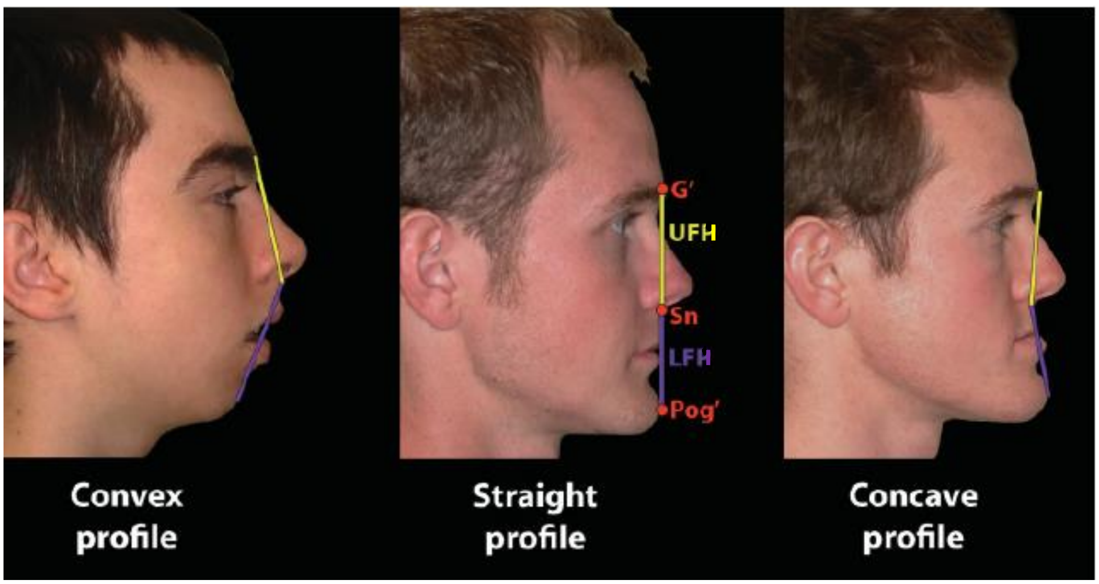


Figure 10. Facial Profile Contours (convex, straight and concave). The line from Glabella (G') to Subnasale (Sn') and Sn' to Pogonion (Pog') must be parallel (Straight profile). Reproduced with permission from Wiley and Sons.

A **straight** profile suggests a Class I dentoalveolar relationship and an orthognathic or well-balanced sagittal skeletal relationship. A **convex** profile usually implies a Class II dentoalveolar and sagittal skeletal relationship; it may be due to sagittal maxillary excess, sagittal mandibular deficiency (and/or sagittal chin deficiency) or a combination of the two. Finally, a **concave** profile usually indicates a Class III dentoalveolar and sagittal skeletal relationship; it may be due to sagittal maxillary deficiency, sagittal mandibular excess (and/or sagittal chin excess) or a combination of the two.

Generally, straight profiles are considered more attractive than convex or concave profiles.[87-89] A slightly retruded chin was considered a female beauty ideal in the first half of the last century.[15] Nowadays, a straight profile with a rather dominant chin is deemed esthetic.[15] Additionally, since the chin provides harmony and character to the face, a strong chin or prominent jawline is considered to be esthetically pleasing, especially in males.[11]

Multiple studies also looked at ethnic differences in profile types.[90-92] For example, Korean American patients have been found to prefer a more protrusive nose for females and a more retrusive chin for males.[90] Similarly, McKoy-White et al.[91] compared attractiveness of black female profiles among black female patients, black orthodontists, and Caucasian orthodontists. It was found that Caucasian orthodontists preferred flatter profiles than did the black women, who in turn preferred fuller profiles than the black orthodontists. Overall, the greatest differences among and between ethnic groups seem to be in the dentoalveolar region.[92] In a study looking at lip morphology in different profiles, fuller lip positions were preferred for the more extreme retrognathic and prognathic profiles, whereas more retrusive lip positions were preferred for the more average profiles. Similarly, Hier et al[93] found that untreated individuals preferred fuller lips than did orthodontically treated individuals, for both males and females. It has been shown that about half the population cannot characterize their own profile.[94] However, subjects who perceive their own profiles as being different from average are more likely to be unhappy with their facial appearance.[94] As well, orthodontic patients that underwent orthognathic surgery are less accepting compared to orthodontists when it comes to evaluating their facial profile.[95]

1.6.3.1 Chin and Lower Face

The chin is an essential esthetic pillar, especially in profile view. The chin establishes much of the character of the lower face and society tends to associate it with personality: a strong chin is synonymous with courage and masculinity, whereas a recessive chin represents a repressed, or introverted person.[96] A weak or soft chin is also associated with femininity.[97] Excessive chin prominence is unattractive; conversely, a deficient chin leads to an indistinct lower face merging with the neck, which may be even more unattractive.[98]

The esthetic position of the chin is determined by two factors[48,96,99,100]:

1) The amount of anteroposterior, vertical and transverse bony projection and,

2) The amount of soft tissue that overlays that bony projection

Morphology and aesthetics of the chin is closely related to the lower lip and mentolabial fold. The terms ‘chin excess’ and ‘chin deficiency’ may be used to describe chin deformities in the sagittal or vertical plane. The sagittal position of the chin is indicated by the soft tissue pogonion (Pog′, the most prominent point on the soft tissue contour of the chin, in the midsagittal plane). *Progenia* is the term used to indicate that the chin is protrusive (too far forward) in relation to the rest of the craniofacial complex. *Retrogenia* is a term used to indicate that the sagittal *position* of soft tissue pogonion (Pog′) is retrusive (too far back) in relation to the rest of the craniofacial complex. Progenia and retrogenia are mainly influenced by 1) morphology of the chin (microgenia or microgenia) 2) sagittal position of the mandible 3) relative position of the lips being positioned too far forward or posteriorly in relation to the craniofacial complex and 4) rotation of the occlusal plane.[13] An excessive vertical growth pattern may result in a decreased chin projection while a horizontal growth pattern may result in an increased chin projection.[48] It is important to differentiate between the etiology of *progenia* and *retrogenia* since treatment may differ. For example, genioplasty can effectively camouflage the perception of a weak chin, but cannot correct the retrusive lower lip and sagittal skeletal dysplasia.[13]

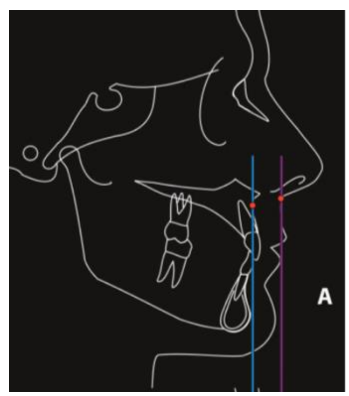


Figure 11. Normal Chin Prominence using True vertical plane through subnasale. Reproduced with permission from Wiley and Sons.

The degree of projection of the chin may be evaluated using multiple analyses. The most used and modern analysis is the Zero-Degree Meridian by Gonzalez-Ulloa.[101] For normal chin and profiles, the soft tissue pogonion (Pog′) should be on a vertical line dropped from soft tissue nasion, perpendicular to the Frankfort Horizontal plane.[101] This analysis is easy to use and has been demonstrated to be in accordance with the idealized profiles of classical and modern canons of beauty.[13] As well, the *true vertical plane through subnasale* is widely used and is a reasonable tool for evaluating lower face relationships (Figure 11).[102] In this analysis, the sagittal position of soft tissue pogonion should be 1-4mm posterior to the subnasale vertical (SnV) line. In general, women tend to accept a slightly reduced chin projection, whereas men tend to accept slightly increased chin projection.[103] Thus, this is influenced by the relative prominence of the nose and lips in both sexes.[13] A more common measurement for assessing adequate chin projection is its relationship to the lower lip. A man's chin should approach, but not exceed, a vertical line from the lower vermillion border in repose. A woman's chin, however, is ideally situated 2 to 3 mm behind this line.[103] In a recent study, chin protrusion or retrusion of more than 4mm from the Zero-Degree Median line were considered unnoticeable by clinicians and laypeople while surgery was desired for protrusion of 6mm and a retrusion of 10mm.[98] However, these findings were in contrast to other studies where retrusive chins were perceived as being less attractive than protrusive chins.[88,104,105] Nevertheless, these studies all agree in stating that a chin that is too protrusive or retrusive is considered unaesthetic.[88,104,105]

1.6.3.2 Mentolabial Fold

The mentolabial fold, also known as the mentolabial sulcus or labiomental sulcus, is a region evident in frontal and profile views and a critical esthetic parameter of the lower face. It is the anatomic separation of the lower lip and the chin (Figure 12). The fold is usually located halfway in between Stomion (St) and Menton (Me') in the lower face thirds, creating the separation between the second and last third.[48] The sulcus is affected by facial height, overjet, and chin projection.[99] The depth of the mentolabial fold is measured by the distance between soft tissue B-Point (B') to a vertical line from Labrale inferius (Li) to soft tissue pogonion(Pog')(Figure 12). The mentolabial fold should measure approximately 4mm; it is usually increased in males due to a larger chin prominence.

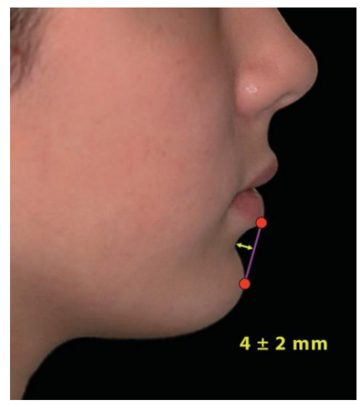


Figure 12. Mentolabial fold dept and angle. Reproduced with permission from Wiley and Sons.

More shallow folds may appear more attractive in short face individuals making the face look longer while a deeper mentolabial fold may appear more attractive on patients with increased LAFH, deemphasizing the height of the lower face.[106] Finally, the mentolabial fold plays a major role in the esthetics and treatment planning of a retrognathic Class II malocclusion case, especially when it comes to orthognathic surgery and functional therapy. Therefore, it is important to understand the advantages of the mandibular advancement versus the camouflage advancement genioplasty.

1.6.3.3 Nasolabial Angle

From the profile view, an important aspect of facial beauty is the nasolabial angle. It is the angle between a line drawn through the midpoint of the nostril aperture (or columella) to a line tangent from the upper lip (subnasale-stomion). The normal range of the nasolabial angle is 90° to 120° degrees and can be altered by upper teeth proclination, anteroposterior position of the maxilla, lip fullness and tip of the nose position (Figure 13).[107] In general, females tend to have a more obtuse nasolabial angle than males.[13]

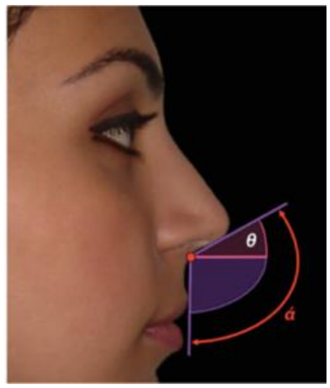


Figure 13. Nasolabial angle ranges from 90° to 120°. Reproduced with permission from Wiley and Sons.

1.6.3.4 The Nose

The nose occupies the central position of the face and is the most prominent part of the facial profile. The nose not only has profound dominating effect on the profile but also has emotional,

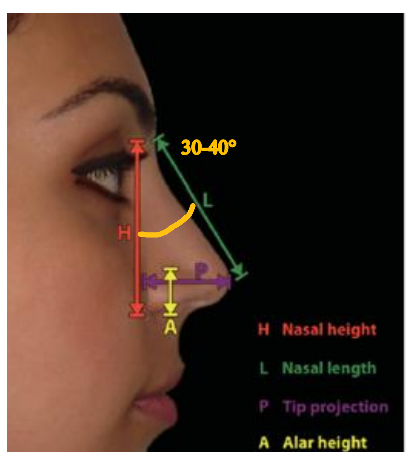


Figure 14. Nasal height, length and projection. Reproduced with permission from Wiley and Sons.

cultural and functional significance. The proportions of the nose are illustrated in Figure 14. The Nasal Height is the vertical distance from Nasion (N') to Subnasale (Sn) while the Nasal Length (nasal dorsum) is the distance form Nasion (N') to Nasal tip or Pronasale (Prn) (Figure 14).[13] *Nasal tip projection* or *nose protrusion* describes the distance from nasal ala to nasal tip. For esthetic results, the nasal tip should project between 30° to 40° from the profile line (Figure 14).[96] When the nasal tip extends at an excessive distance from the face (increased nose projection), it is perceived as disproportionately prominent and unaesthetic. In general, males have larger and more pronounced noses than females.[5,13,76,77]

1.7 Transverse Facial Proportions – The Central Fifths

The central fifths or rule of fifths is convenient to assess the ideal transverse facial dimensions and symmetry. The face is divided into five equal parts from the helixes of the outer ears; each section should be roughly equal to one eye width (Figure 15).[48] The middle fifth is delineated by the inner canthi of the eyes (En' -En') and should be coincident with the ala of the base of the nose (Al'-Al'). In appealing faces, the medial two fifths of the face, outlined by the outer canthi of the eyes, should be coincident with the gonial angles of the mandible or bigonial width (Go'-Go'). This bigonial width should be approximately 70 – 75% of bizygomatic width (Zy'-Zy').[48] Finally, the outer two-fifths of the face are measured from the outer canthi of the eyes (Ex') to the helix of the ears.[99]

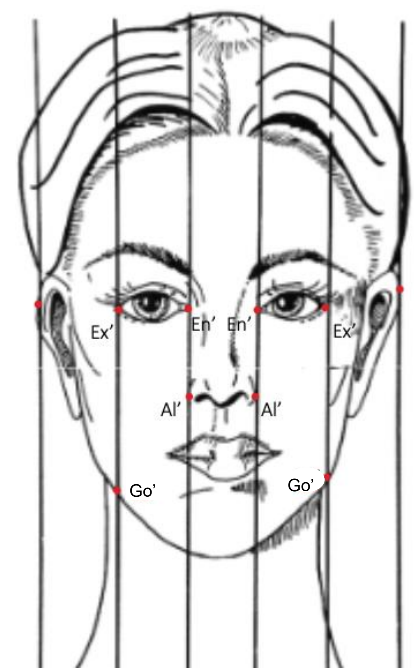


Figure 15.Sagittal Facial Proportions: "the rule of fifth". From the midsagittal plane, the face is comprised of equal fifths, all approximately equal to one eye width. Reproduced with permission of SAGE Publications.

These fifths should be distributed equally in the frontal view of the face.[66] Additionally, they help in evaluating the width of some critical features of the face (e.g., nose, mouth, eyes). For example, in attractive faces, the width of the mouth represents 1.5 times the width of the nose (Figure 16C). [108] In Chinese patients, the width of the mouth is found to be closer to 40% of the facial width.[109] The nose and the chin width are within the central fifth and the interpupillary distance is equal to the width of the mouth.[17,66] The Bizygomatic width (Zy'-Zy') is 4 times the width of the nose (Al'-Al').

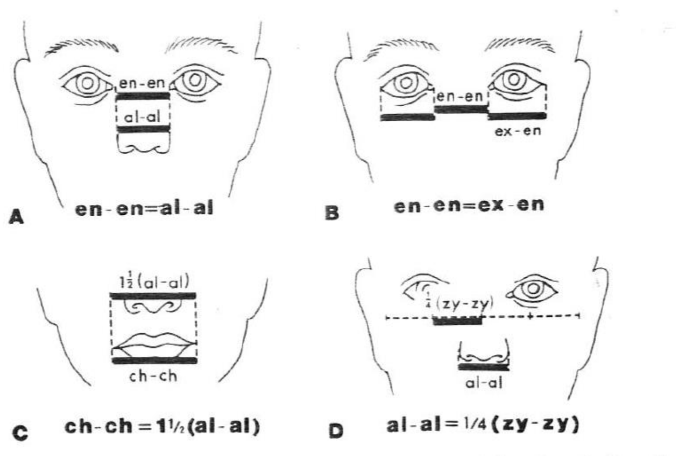


Figure 16. Sagittal Facial Canons Adapted from Farkas et al. A. The Alar base (Al'-Al') should equal the middle fifth or distance between the eyes (En'-En') B. The intercanthal distance should equal an eye width (En'-Ex') C. The width of the mouth (Ch'-Ch') represents 1.5 times the width of the nose (Al'-Al') D. The Bizygomatic width (Zy'-Zy') is 4 times the width of the nose (Al'-Al'). Reproduced with permission from Elsevier.

1.7.1 Alar base

The alar base width (Al'-Al') should be approximately the same as the intercanthal distance (En'-En'), which should be the same as the width of the eye (En'-Ex')(Figure 16A). Guyuron[107] has suggested that the alar width may be 1 or 2 mm wider than the intercanthal width. In non-Caucasian ethnicities, this standard is often too narrow, and the alar base is usually wider.[110] In Chinese patients, for example, both the intercanthal width and alar width are increased.[109]

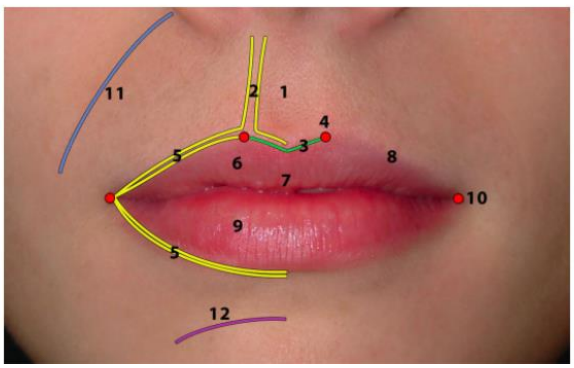
1.7.2 Malar Eminence

The malar eminence or "cheekbone" should be the most prominent bony projection in the midface. It is formed by the underlying zygomatic bone. Full and high cheekbones are considered highly desirable for facial attractiveness and are associated with youth. Generally, the youthful midface has a rounded cheek with smooth transitions to the lower lid and the nose.[111] Hypoplasia in this area imparts a certain degree of flatness that is easily noticeable.[112] Ideally, the lower third of the iris should be covered by the lower lid, which should be supported by the bone of the lower orbits and midface.[17,48] A LeFort 1 procedure will often improve the esthetics of a midface deficiency.[113] Females are known to have more pronounced cheekbones and soft tissue thickness in the zygomatic region, while males have thinner cheeks, and cheekbones that appear less prominent due to other prominent facial structures (e.g. the nose).[23]

1.8 Lower Face

1.8.1 Lips

The lips represent a crucial component of attractiveness and are perhaps the most mobile expressive esthetic unit of the face. The lips are a complicated and complex structure, composing of multiple subunits. Anatomy of the lips from the frontal view is illustrated in Figure 17. The lateral boundary of the upper lip on each side is the nasolabial groove which separates the lip from the cheeks; the lower lip is separated from the chin by the mentolabial groove. The upper lip form, with the cupid's bow, is a result of the maxillary process fusion with the midline of the nasal process during embryonic development.[13]



1 Philtrum
2 Philtral ridges/columns
3 Cupid's bow
4 High points of the vermilion (bilateral)
5 White roll
6 Upper lip vermilion
7 Upper lip tubercle
8 Vermilion border (mucocutaneous junction)
9 Lower lip vermilion
10 Oral (labial) commissures
11 Nasolabial groove
12 Mentolabial groove

Figure 17. Anatomy and Terminology of the Lip. Reproduced with permission from Wiley and Sons.

1.8.1.1 Lip Prominence

Lip prominence (or protrusion/retrusion, sagittal position, or projection) is evaluated relative to the prominence of the nose and chin in profile view. Lip prominence depends on lip thickness/fullness, LFH and position of the incisors.[114,115] Lip prominence is an important factor to consider in orthodontic treatment since retraction or protraction of incisors can affect the lip protrusion; thin lips follow the teeth more while thick and flaccid lips may not be altered by teeth position.[79,93,115-120] Evaluation of lip prominence should be done with the patient in natural head position and the lips in repose. A number of analyses have been used and described to aid in the evaluation of the *relative prominence* of the upper and lower lips to the facial profile. Irrespective of the analysis employed, the ideal protrusion of the lips has been described as the upper lip having a slightly greater protrusion than the lower lip.[13,111,118,121-126]

Fuller and protrusive lips are preferred, especially in females and in retrognathic and prognathic profiles.[30,114] As well, lip fullness is influenced greatly by ethnic variations. African Americans tend to have the greatest lip thickness and studies show that they do prefer a fuller, more protrusive lip as well.[110] Studies reveal that eastern Asians prefer smaller lips relative to Caucasians, while Hispanics prefer thicker lips.[124] Caucasians of northern European backgrounds have relatively thin lips compared with Caucasians of Eastern European or Middle Eastern.[123] A recent study on Saudi patient reveals that they have a more convex profile with prominent upper and lower lips.[127]

1.8.1.2 Vertical Lip

The proper term used to indicate the red part of the lips in its vertical dimension is *vermilion exposure*. It consists of the relation between the *upper lip* or *upper vermilion height* [(Labrale Superius (Ls) to Stomion Superius (Sts)] and the *lower lip* or ***l****ower vermilion height* [Stomion inferius (Sti)- Labrale Inferius (Li)](Figure 17-6,9). Equilibrium of the upper and lower lip is

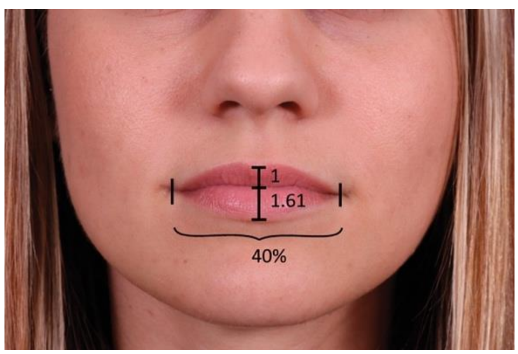


Figure 18.Well-Proportioned lips with a vermillion exposure ratio of 1 to 1.6 and a width of the mouth consisting of 40% of the lower face width. Reproduced with Permission from Georg Thieme Verlag KG.

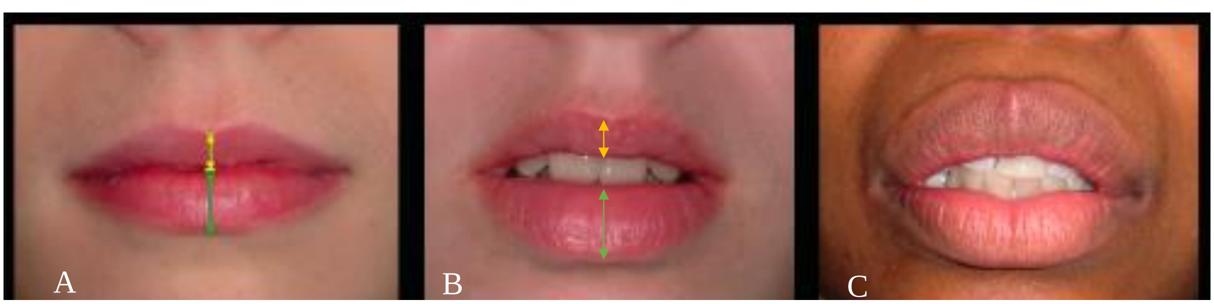


Figure 19. Difference in vermilion exposure or height. The ratio between upper and lower vermilion should be 1:1.6 (A) to 1:2 (B). A 1:1 ratio can often result in a "fish like" appearance (C). Reproduced with Permission from Wiley and Sons.

necessary for a natural and esthetic appearance. What is essential in the relation between the upper and lower lips is their proportion to each other rather than their relative heights. The ideal ratio of upper to lower lip heights is considered to be between 1:1.6[111,128,129] to 1:2 (Figure 18).[125] The ratio is increased in women since they have proportionally greater vermilion exposure than men. Popenko et al.[125] found that an upper to lower lip ratio of 1:2 is deemed most attractive while a ratio of 2:1 is considered least beautiful, especially in Caucasian women. If this ratio is not respected and the upper vermillion shows more than the lower, the patient will often have a “fish-like” appearance (Figure 19C). African populations have the most considerable vermilion height while the Caucasians have the smallest (Figure 19A).[130] African Americans tend to have an increase upper lip height while Oriental patients have a similar lip height as Caucasian.

1.8.1.3 Lip contour

Lip contour can be evaluated in frontal (lip curvature) or profile view (lip curl or inclination). In frontal view, the upper lip contour is determined by the mid-philtrum (Sn to Sts) and the commissures height (from commissure to horizontal line from Subnasale) (Figure 20A).[48] The philtrum height should be shorter (1-3mm) than the commissure height in children and adolescent and equal in adults (Figure 20A).[131,132] A significant shorter philtrum height may result in an unattractive upper lip line and a gummy smile (Figure 20B).[13,48] At rest, the upper lip should cover 2/3 of the maxillary incisor crowns and the interlabial separation should be no more than 2- 3mm.[13,28]

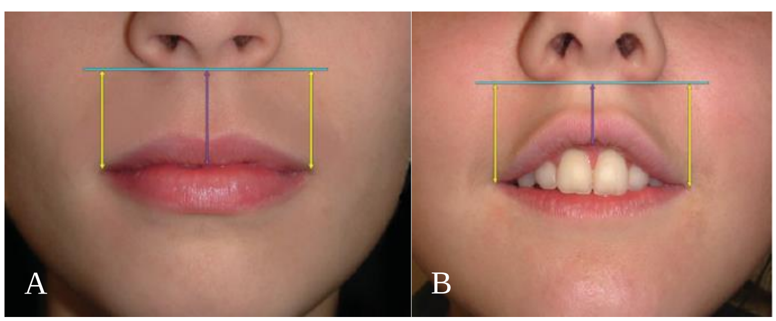


Figure 20. A) Philtrum and commissure height should be approximately equal in adults with lips in contact. B) A shorter philtrum results in an unattractive upper lip line. Reproduced with Permission from Wiley and Sons.

From the profile view, attractive faces have a nice curve to the upper lip. A flat lip curve may be seen in dentoalveolar retrusion of the maxillary anteriors or in maxillary retrognatia (Figure 22).

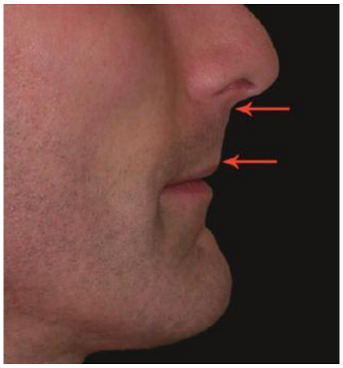


Figure 22. Reduced upper lip curl; Flat upper lip. Reproduced with permission from Wiley and Sons.

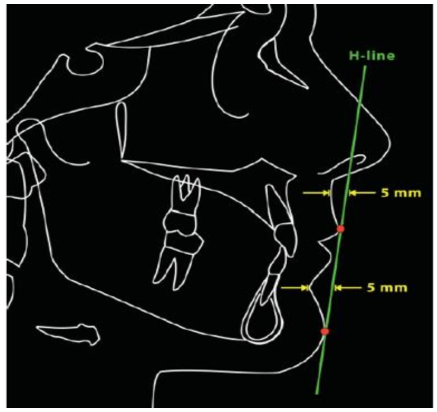


Figure 21. Upper and lower lip sulcus depths. Reproduced with permission from Wiley and Sons.

Excessive curve is often seen in Skeletal Class II patient with decreased LFH, mandibular overclosure or proclined maxillary incisors (Cl II division 1). The curl of the lips is evaluated by using the H line (chin to upper lip) and evaluating the upper and lower lip sulcus; there should be a distance of 5mm from the sulcuses to the H line for both upper and lower line (Figure 21).

1.9 Sagittal Skeletal Dysplasia (SSD) and Facial Attractiveness (FATT)

The creation of an esthetic or "harmonious" face requires a condition where the skeletal bases of the maxilla and mandible are of the correct size relative to each other and the teeth at rest are in correct relationship in all three planes of space.[7,8] Dentofacial relations that do not follow this model are known as *SSD* and *malocclusion* and are characterized by specific features. The *sagittal* relationship of the mandible to the maxilla may be described as orthognathic (skeletal Class I), retrognathic (skeletal Class II) or prognathic (skeletal Class III). For example, Class II malocclusions can be characterized by a large overjet, a convex profile, a retrognathic mandible, a prognathic maxilla, proclined or retroclined upper incisors, and incompetent lips.[7,11,88,133] Often, the jaw relationship and soft tissue profile will correlate (e.g., Class II SSD with convex profile).[133] The patient's chief complaint will often be related to the facial consequences of these malocclusions, and not necessarily to the dental relationship. Interestingly, patients with Class II malocclusions accounts for 15-20% of all patients normally seen in an orthodontic office [17] and the majority (41-80%) of these patients have a chief complaint of aesthetics that prompt them to seek treatment.[9,10] One of the principal facial features believed to make these patients less attractive is the retrusive position of the chin leading to a convex profile.[11] However, compensations (dental or soft tissues) in these patients may act as a camouflage to provide a more balanced profile and facial esthetics.[12] Additionally, the decrease in the perceived FATT for patients with convex profile may also be due to an increase in face height.[16]

1.9.1 Measurement of Skeletal Sagittal Discrepancy Severity

The most commonly used SSD indicator so far has been the ANB angle.[134] It provides the range of severity for skeletal class II and III relationships. The ANB angle represents the differences between the SNA and SNB angles, providing an indication of the sagittal disharmony between the maxillary and mandibular apical bases (Figure 23). [13,134,135]

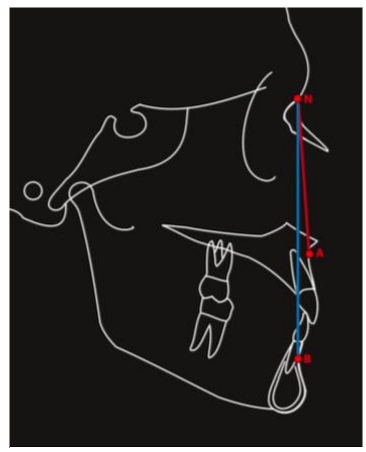


Figure 23. The ANB angle represents the difference between the SNA and SNB angles, providing an indication of the sagittal skeletal discrepancy (SSD) between the maxillary and mandibular apical bases. Reproduced with permission from Wiley

The ANB value can be positive or negative depending on the relation of NA and NB lines. If point A lies anterior to anterior to NB, the angle is positive; if point A coincides with NB, then the ANB angle is 0; and, if point A lies posterior to NB, then the ANB angle will be negative.[136]

An ANB angle ranging from 2 ± 2° degree is considered to be a *skeletal sagittal Class I discrepancy*; the maxillary and mandibular skeletal bases are in normal relationship to one another (orthognathic).[137]

An ANB angle greater than 3.6° is considered to be a *skeletal sagittal Class II discrepancy*; there is *relative* maxillary prominence i.e., the mandible is positioned further back (retrognathic) in relation to the maxilla than in skeletal Class I individuals.[17]

An ANB angle less than 0° is considered to be a *skeletal sagittal Class III discrepancy*; the mandible is *relatively* prominent i.e. the mandible is positioned further forward (prognathic) in relation to the maxilla than in skeletal class I individuals.

1.10 Measurements of Facial Beauty

Various techniques have been used in the past to evaluate facial aesthetics, such as silhouettes, photographs, line drawings and cephalometric analysis.[5,16-18] The main drawback of these methods is that it provides a 2D view of a 3D face. For example, data collection in cephalometric analyses do not include the curving of, and changes in, form and has been shown to have low precision due to the difficulty of landmark identification.[138,139] Considering the advancements made in digital imaging, it has since become possible to use 3D facial images with a higher level of informational content.[140] 3D imaging can, for the most part, help replicate the anatomy of the bone, soft tissue, and teeth.[19] Consequently, these structures can be used to evaluate the dentoskeletal and craniofacial relationships in the measurement of FATT.[20] Recent studies have used 3D imaging such as 3D laser scanning, structured light technique, stereophotogrammetry and 3D surface imaging systems (3dMD) to evaluate facial beauty.[60,61,141,142] These methods allow a reproductive image of the facial structures but lack precision when it comes to identifying skeletal structures underlying the soft tissues.[19] Hence, to be able to analyze the hard tissues of the face, these techniques often require superimposition of images which can lead to errors at the time of data collection and analysis.[19,22]

A cone beam computed tomography (CBCT) is an imaging technique that can acquire and relate all structures of the face in a single run. Indeed, studying the relation of the soft and underlying hard tissues is a key factor in using CBCT scans instead of other 3D imaging approaches to evaluate facial beauty.[19-22] However, one of the main drawback of CBCT imaging is the increased radiation exposure as compared to traditional panoramic and cephalometric radiography.[19,21,22] Some could argue that for evaluating FATT, a possible disadvantage of CBCT imaging is that the hair, eye color, skin texture and skin color are not discernable.[19,21,22] This could therefore impact assessment of FATT. However, this could actually be beneficial since all extrinsic and intrinsic distracting variables (such as hair style, make-up, and skin complexion) that could influence an evaluator’s aesthetic score rating will be eliminated.

1.11 Visual Analog Scale and Rating of FATT

Multiple scales or tools have been used for assessment of FATT; the Likert scale and the Visual Analog Scale have been the most commonly used. The Likert scale is a five (or seven) point scale which is used to allow the individual to express opinion on how much they agree or disagree with a particular statement.[143] Even though it is simple and easy to use, the Likert scale uses ordinal data and doesn't measure the exact difference between scores. This sometimes fails to evaluate the true attitudes of respondents.[143] Therefore, the visual analog scale (VAS) has been extensively used for FATT rating.[144] It is a simple and rapid method and consists of a horizontal line, 100 mm in length, anchored by word descriptors at each end such as "very unattractive" (0 mm) to "very attractive" (100 mm).[145] Compared to a simple descriptive ordinal scale, VAS is more sensitive to small changes and can be analyzed as continuous measures, thus allowing greater precision in data analysis.[146]

1.12 Geometric Morphometrics

Shape analysis plays an important role in many kinds of biological studies since it can help analyze the morphological shape variations and transformation of species.[147] Traditionally, anthropometric measurements for facial analysis were based on linear measurements, neglecting the amount of shape information that could actually be collected.[147] As well, analyses of morphology relied heavily on qualitative descriptions and manual measurements, for which inter-observer error presented major challenges.[147] With the advent of 3D imaging technology, geometric morphometrics (GM) became an essential tool to mathematically compute landmark correlates to explain shape variations.[148] GM is now the method of choice for analysis of craniofacial shape; it focuses on the coordinates of landmarks and the geometric information about their relative positions.[148,149] Hence, for evaluation of facial beauty, GM offers precise analyses while serving the important purposes of visualization, interpretation and communication of results.[60]

To be able to visualize these shape variations, we need to perform a Procrustes superimposition of our landmarks. Mainly, we remove any differences in scale/size, orientation and position of the landmarks to be able to get correlates of pure shape of our sample subjects (Figure 24A).[147] Thus, we center the landmarks to their centroid or geometric center (0,0,0) and then re-size them to the same centroid size (square root of the sum of squared distances of a set of landmarks from their centroid). [150] Next, GM has the ability to submit the landmark coordinates to multivariate statistical analysis to allow us to look at 1) specific effects on shape and 2) how these identified effects affect shape (Figure 24).[147] We can then visualize these shape differences/variations with vectors of landmark displacement (Figure 24B).[150] Using these shape vectors we are then able to morph or digitally transform one image into another to better visualize the shape changes in three dimensions (Figure 24C,D).[151] Therefore, the use of GM analysis offers a solution to quantify and visualize variations in facial shape changes across individuals in studies of FATT.[152]

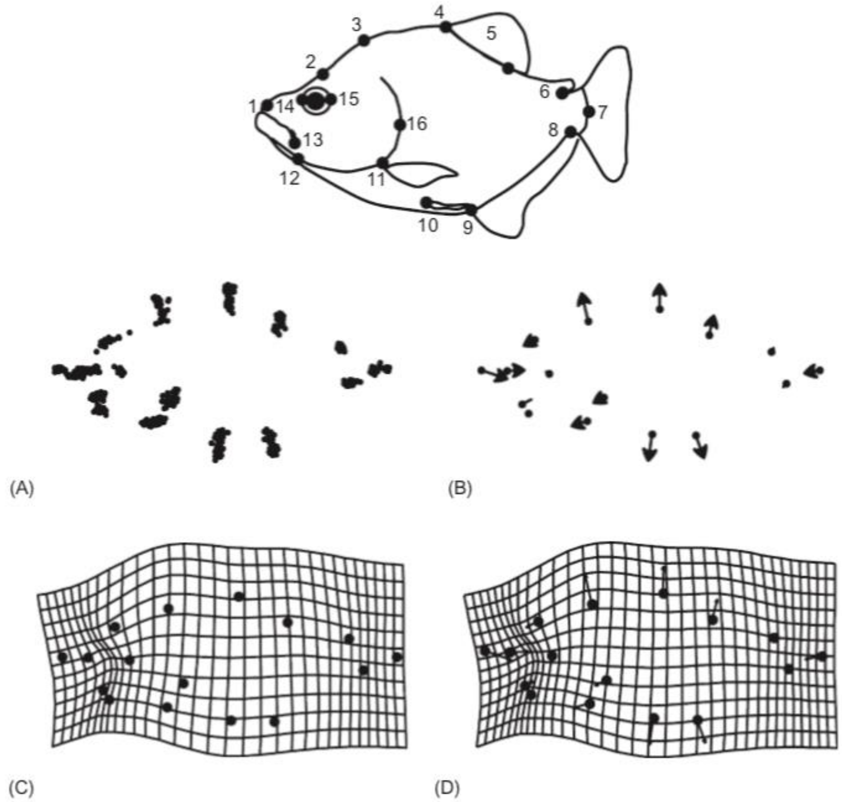


Figure 24. Example of the use of geometric morphometrics to look at the shape change. (A) Configuration of landmarks of different specimens (B) Covariance between shape change depicted by vectors of relative landmark displacement (C) The shape change depicted by deformed grid (D) The shape change depicted by deformed grid and vectors of displacement. Reproduced with Permission by Elsevier.

1.13 Importance of Orthognathic Surgery for Treatment of SSD

Orthognathic surgery or corrective jaw surgery leads to improvements in patients' occlusion, function, facial esthetics, self-confidence, and quality of life.[153] The most frequent motive for requesting orthognathic treatment appears to be a desire for improvement of facial appearance.[154] The number of orthodontic patients requiring orthognathic surgery varies between 1% to 5%,[154,155] with twice as many females compared to males.[153,156,157] Of these patients, 41% to 59% require surgery for skeletal Class II correction and 35% to 47%

for skeletal Class III correction.[158,159] Skeletal Class II malocclusion is twice as prevalent in black and Hispanic people as in white people,[159] whereas the prevalence of skeletal Class III is three and two times higher in Asians and Hispanics (Mexican Americans), respectively, compared to blacks or whites.[159]

To achieve good results with surgeries involving the lower face, the orthognathic surgeon, orthodontist and patient work as a team to achieve the desired result. In general, patients are highly satisfied (90%) with orthognathic surgery.[154,160] However, multiple factors such as a lack of a thorough clinical analysis and diagnosis, a wrong treatment plan, and an improper surgical technique[161,162] can lead to a failure from an aesthetic point of view.[163] For example, a genioplasty is an extremely technique-sensitive procedure and often relies on the surgeon's esthetic expertise and judgement; if not planned or executed correctly, it can lead to unaesthetic results in chin size, width and anteroposterior position.[162,164]

1.13.1 Computer Aided Surgical Simulation (CASS) in Orthognathic Surgery

Orthognathic treatment protocol usually consists of three stages: preoperative orthodontics, surgery, and post-operative orthodontics.[157] Traditional treatment planning for orthognathic surgery involves diagnosis with two-dimensional (2D) cephalometric radiography, model surgery on plaster dental cast, and fabrication of intermediate and final occlusal splints. This conventional process delivers generally satisfactory outcomes, but has a number of limitations in terms of accuracy.[165,166] Currently, Computer Aided Surgical Simulation (CASS), an online software platform option to perform different 3D surgical simulations is used by surgeons. From the pre-operative CBCT images and intra-oral scans, the surgeons is able to predict the corresponding hard tissue and soft tissue results, as well as to facilitate the transfer of the virtual surgical plan to the operating room using 3D printed splints and guides.[167] CASS therefore offers a powerful visual option and is an efficient and accurate aid for improving surgical outcomes.[168,169] Indeed, the accuracy of a number of maxillary and mandibular surgical techniques at the hard tissue levels has been highly improved with the adoption of CASS and surgical guides.[165,166] However, despite the accuracy of CASS in predicting dento-skeletal relationships, soft-tissue forecast does not always exactly predict the final results, especially for the lower lip and chin area.[170,171] A recent study comparing the accuracy of the actual outcome to the simulated plan found that sagittal positioning of the chin following osseous genioplasty was the least accurate in virtual surgical planning.[172] Although the final chin position in genioplasty cases is usually virtually planned by the surgeon, freehand surgical techniques are still being used in the operating room i.e., with no printed guide. As well, problems with surgical outcomes arise from the poorly planned CASS, which is reflected on the splint. Many surgeons continue to adopt their own ideal aesthetics of chin position[172], a decision that oftentimes results in surgeon-related errors or differences,[171,173] and patients' dissatisfaction with the esthetic outcome.

The trend in recent years among patients going for surgery is an increasingly high expectation and demand of aesthetic improvements. A significant number of patients are asking for repeated orthognathic surgery to achieve facial aesthetics improvement, especially of the lower jaw and chin.[168,174] To provide better results, a clinician must take into account the lower facial third and the patient's gender.[164] Inaccurate preoperative analysis and lack of surgeon's expertise and judgement of profile esthetics can lead to unintentional and unfavorable esthetic outcomes, such as over- or under-correction of the chin's sagittal position.[103,162,173] Therefore, standardized sets of shape correlates for FATT to aid in surgical planning would be of significant help to surgeons.

CHAPTER 2
RESEARCH OBJECTIVES AND HYPOTHESES

2

2.1 Study Rationale

A balanced maxillary-mandibular skeletal relationship is critical for optimal esthetics. Not surprising, therefore, is the finding that patients with SSD are often dissatisfied with their facial esthetics, an essential and valued aspect of human life.[1] The use of CBCT offers a powerful imaging technique for assessment of FATT since it acquires and relates the 3D structures (both soft and hard tissues) of the face in a single run.[22] Assessment of FATT in these scans possibly has the advantage of removing extrinsic and intrinsic distracting variables (e.g., hair style and/or make-up, skin complexion) with a focus on only the correlates of the hard and soft tissues.[19] Furthermore, studies have shown that males and females possess distinct facial features, e.g., females tend to have fuller lips and smaller chin compared to males.[11,14]

The facial characteristics of patients with SSD at the 3D level have not been clearly defined in terms of the morphological shape or the impact of sex differences that contribute to attractiveness versus non-attractiveness. In an era where patients are increasingly requesting esthetic improvements, a better knowledge of such attributes using GM shape analysis will guide orthodontists and surgeons in the treatment planning of patients with SSD.

2.2 Study Hypothesis

1. Attractive faces of patients with SSD possess defined 3D facial characteristics.
2. Faces of patients with SSD possess defined 3D correlates of sexual dimorphism.

2.3 Aim of the study

For this study, we aimed to characterize the following in the CBCT scans of subjects with SSD:

1. The 3D morphological correlates of FATT, and;
2. The 3D morphological correlates of sexual dimorphism.

CHAPTER 3
MANUSCRIPT

3

Three-Dimensional Shape of Facial Attractiveness in Patients with Sagittal Skeletal Discrepancy

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Short Title: Three Dimensional Morphological Correlates of FATT

Declaration of interest: None

MESH Keywords: Attractiveness, Skeletal Malocclusion, Sexual Dimorphism, Three-Dimensional, Geometric Morphometrics

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ABSTRACT

Three-Dimensional Shape of Facial Attractiveness in Patient with Sagittal Skeletal Discrepancy

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Objective: Dissatisfaction with facial esthetics is one of the chief complaints of adult patients with Sagittal Skeletal Discrepancy (SSD). In this study, we aim to characterize the three-dimensional (3D) shape correlates of facial attractiveness (FATT) and sexual dimorphism (SD) from cone-beam computed tomography (CBCT) scans in subjects with varying degrees of SSD.

Methods: Our sample consisted of forty anonymized CBCT scans of adults (18 to 35 years old) with ANB angle values of 0° to 10°. Next, 100 laypeople rated the FATT and the sexual dimorphism (M/F) of each model using a 100mm Visual Analog Scale (VAS). We identified landmarks to characterize external facial and internal skeletal shape and used Procrustes-based geometric morphometrics (GM) and multivariate linear regression to quantify, test, and visualize shape vectors associated with FATT and M/F VAS scores.

Results: We identified significant associations of FATT and M/F with shape. More anterior and inferior displacements of gnathion and pogonion were significantly associated with more attractive faces (R^2=0.46, b=0,0015, P=0.049), especially in females (R^2 = 0.67, b=0.0027, P=0.006). Prominent cheeks and posterior displacement of the tip of the nose were significantly associated with a more feminine facial appearance ($R^{2=}$0.62, b=0.0013, P=0.192).

Conclusions: We found that the relative antero-inferior position of the chin had the strongest impact on FATT compared to other facial features. As well, prominent cheeks and posterior displacement of the tip of the nose were significantly associated with a more feminine facial appearance. These results provide guidance in the orthodontic/surgical treatment planning of patients with SSD with potential to help predict the amount of surgical advancement needed to improve FATT in individual faces, taking sex into consideration.

3.1 Introduction

Facial attractiveness (FATT) is an important and valued aspect of human life.[1] Individuals possessing attractive faces have been shown to lead more favorable lives and are more likely to be hired and promoted for jobs.[3,4] Although universal standards of beauty are frequently posited on the basis of abstract, geometric, or mathematical principles,[6] the perception of beauty is known to vary from individual to individual, and is influenced by the observer's own judgement, ideas, and mood.[5,55,56] This perspective (i.e., "beauty is in the eye of the beholder") is consistent with the idea that the perception of beauty is driven by individual preferences and choices. As a consequence, the principles governing beauty in general and facial beauty in particular are best modelled by measuring individual choices and preferences at a population level.

In orthodontics, facial esthetics are defined in large part by normalized functional and esthetics clinical outcomes. For example, when the skeletal bases of the maxilla and mandible are the correct size and position relative to both each other and to the teeth at rest in all three planes of space they are considered "harmonious"[7,8], while antero-posterior discrepancies between the skeletal bases are labelled sagittal skeletal disharmony (SSD). Interestingly, the chief esthetic complaints of patients in dental or orthodontic offices are most often related to the facial consequences of the SSD, suggesting a direct link between normalized function and the perception of beauty.[9,10] Corrective jaw surgery in these patients is a treatment option that provides a more balanced profile and facial esthetics by surgically realigning the jaw bones relative to the occlusion.[12,174,175] Even though the techniques of corrective jaw surgeries are becoming more precise with modern imaging and software technology[175,176], many parts of the surgical decision making, such as the amount and degree of surgical movement to elicit a good esthetic outcome, remain highly dependent on both the surgeon's individual experience and their perception of facial beauty. Another challenge of jaw surgery is the inconsistency between the estimated and actual soft tissue outcome that will result from displacement of the underlying bony structures to correct the SSD.[166,171,177]

Sexual dimorphism (SD) is an important contributing factor to FATT.[34,65,152] As a group, males and females possess generally recognizable, even if not strictly dichotomous, facial features.[74,75] On average, females have fuller and thicker lips, a smaller nose and chin, and narrower jaws, while males tend to have bigger noses, larger jaws, a stronger chin, smaller eyes, and thinner lips.[14] In profile view, the chin is thought to provide harmony and character to the face while the projection of the nose is considered to represent the largest anatomical feature of SD.[178-182] A slightly retruded chin was considered a female beauty ideal in the first half of the last century.[15] Nowadays, a straight profile with a rather dominant chin has been deemed esthetic, especially in males.[15] In both cases, perceptions of masculinity/femininity, like esthetics, may be modelled as a continuous rather than dichotomous variable.

Various techniques have been used to evaluate facial esthetics, such as silhouettes, photographs, line drawings and cephalometric tracings.[5,16-18] The main drawback of these methods is that they provide at best a two-dimensional (2D) view of the three-dimensional (3D) shape of the face. Recent advances in digital imaging make it possible to reconstruct 3D models of an individual's bone, soft tissue, and teeth.[19] In particular, cone beam computed tomography (CBCT) acquires both the soft and hard tissue structures of the face and skeletal morphology in a single sitting[19-22] and thus enables one to study their relationship when planning for corrective jaw surgery[19,21] A drawback of CBCT imaging compared to the 3D facial photos is that the hair and skin color cannot be reconstructed.[19,21,22] However, in the context of esthetics, this "flaw" is a "feature", since potential confounding extrinsic and intrinsic factors (e.g., hair style, make-up, skin complexion, etc.) that could influence an evaluator are eliminated, allowing them to make their assessment on shape alone. Furthermore, we can use Geometric Morphometrics (GM), a collection of methods for the quantification, comparison, and visualization of 3D shape variation.[183-185] GM enables the modeling and visualization of the effects of covariates (e.g., facial attractiveness, femininity, masculinity, etc.) on shape, thus it is ideal for this kind of study.

The morphological features related to FATT and SD in individuals with SSD have been minimally investigated in 3D as a function of shape and in regards to evaluation by the general population (laypeople).[182,186] In an era where patients are increasingly requesting esthetic improvements, a better knowledge of such attributes will guide orthodontists and surgeons in the treatment planning of patients with SSD, taking sex into consideration. Here, we aimed to characterize the 3D morphological correlates of FATT and SD in subjects with SSD using CBCT. We hypothesized that individuals with SSD possess defined 3D facial characteristics of attractiveness and masculinity/femininity and that the maxillary-mandibular skeletal relationship (ANB) is a significant predictor of observable FATT.

3.2 Materials and Methods

3.2.1 CBCT Sample Data

We examined 440 CBCT scans of the face that were collected during routine orthodontic planning and treatment at UCSF (2004-2007) and previously described by Young et al. (2015).[187] All individuals consented for their data to be used for research purposes (IRB #11-06996) (Appendix A). Each subject was scanned only once with a MercuRay CBCT scanner (Hitachi Medical, Tokyo, Japan) with a total radiation exposure estimated at about 550 μSv.[188] Scanner settings were 110 kVp and 10 mA, generating a total of 512 slices in a 10-second scan, with a 19x19x19-cm field of view and voxel size of 0.38 mm The subjects were seated upright as the x-ray tube and image acquisition screen revolved around their heads. Each subject was instructed to hold still, keep the teeth in occlusion, lips relaxed, not to swallow, and keep the tongue on the roof of the mouth and the head in a natural position. The images were reconstructed in CBWorks (version 2.1; Cyber Med, Seoul, Korea) and Avia (Hitachi Medical) and saved in DICOM format.

Information on each scan included ANB angle classification (measured on the reconstructed cephalogram), sex, and age, with all personal identifiers removed. From the initial pool, we selected 82 CBCT based on the following inclusion criteria (a summary of our selection process for our CBCT scans is illustrated in Figure 25)[16,88,89]:

1. No apparent asymmetries, congenital anomaly or other known syndrome;
2. No obvious vertical disproportions of the lower face; the Eastman normal value for lower anterior face height/total anterior face height (55 per cent) was used with a standard deviation (SD) of 2 per cent[83];
3. Ages 15-35 years old at the time the CBCT was taken, and;
4. ANB angle value of 0° to 10°.

We divided the CBCT dataset into categories of SSD based on the ANB angle: skeletal Class I (ANB of 0 to <3.6°), mild skeletal Class II (ANB of ≥3.6° to <6°), moderate skeletal Class II (ANB of ≥ 6° to < 8°), and severe Class II (ANB < 8°).[17]

3.2.2 3D Models

For each CBCT we generated a 3D model of the external surface and internal skeleton by thresholding in the software Amira (version 6.2, Zuse Institute Berlin, Germany), as previously described by Young et al.[187] Thresholding refers to a value that identifies and defines an isosurface used as the 3D model. One operator (JD) inspected all 3D models in *MeshLab 3D* software (version 1.2.1, Institute of Information Science and Technologies in Pisa, Italy) to detect image artifact or distortion. Furthermore, in order to limit the total time of the experiment (see procedures below) to a reasonable time of 30-40 minutes and to homogenize the distribution of ANB values across the subjects, we selected a convenience sample of 40 CBCT face scans for our experiment (Supplemental Table 1 & Supplemental Table 2). Finally, to evaluate the rater's reliability, we duplicated 8 randomly selected CBCT studies (20% of the total sample, two of each SSD categories). Therefore, the total sample included 48 CBCT scans of 40 individuals, divided as following: Skeletal class I (N=11), mild skeletal class II (N=12), moderate skeletal class II (N=12), severe class II (N=5), and duplicate CBCT (N=8, 2 for each SSD category) (Supplemental Table 1). The number of subjects in the severe class II group is low (N=5) since we excluded six scans due to poor imaging resolution.

3.2.3 Assessors

We recruited 108 laypeople aged 18 years and older without dental knowledge or experience to rate FATT and masculinity/femininity (M/F) of the 3D faces reconstructed from each of the 48 CBCT studies. Before the assessment, the assessors filled a demographic questionnaire (Appendix C) and the State-Trait Anxiety Inventory (STAI)[189] (Appendix C). The latter was used to evaluate the assessors' anxiety, which has been previously associated with lower judgement of attractiveness.[55,56] We excluded assessors with a score over 52, as this threshold has been documented to indicate a tendency for anxiety disorder.[55]

3.2.4 Rating Procedures

We positioned the 48 selected CBCT face scans using the Frankfort horizontal (lower margin of eye socket to notch above tragus of the ear) as a reference plane and aligned the faces using the interpupillary line in frontal view. We created video clips showing each face slowly rotating around a vertical axis at the center of the head and perpendicular to the Frankfort horizontal. The faces moved from right to left profile view with a pause in frontal view (Supplemental Video 1).

The assessors were invited into a quiet seminar room (Appendix E) in small groups of 15 to 20. An operator (JD) projected the 48 CBCT video clips (Supplemental Video 1) on a large screen (120x90 inch) in random order using PowerPoint 2016 (Microsoft, PowerPoint for Mac, version 16.36). One example CBCT clip was displayed to raters before starting the actual evaluation. All participants were able to see the entirety of the images and sat at approximately the same distance from the screen. No information was provided about the age, sex or ethnicity of the 3D face models. Next, the assessors rated each face for FATT and for SD using 100 mm Visual Analog Scale (VAS) with the following left and right anchors: “very unattractive” and “very attractive” for FATT, and “Male” and “Female” for SD (Appendix D).[144,145] The assessors were given a total of 20 seconds to view and rate the images with a transition of 5 seconds between the images. The assessors were not able to go back to a previous image and were not allowed to talk or eat/drink during the process. The total length of time needed to view all images and complete the questionnaires was approximately 40 min. The VAS scales were then measured by one investigator (JD) and averaged for each face.

The raters participated on a voluntary basis and compensation was provided. All procedures were approved by the University of Toronto Research Ethics Board (REB #36419) (Appendix A).

3.2.5 Landmarks

To quantify shape we utilized landmark data for both the external face and the internal facial skeleton 3D models as previously reported in Young et al. (2015).[187] A single examiner (NY) identified and recorded the landmark coordinates (x, y, z) from the 3D models using a semi-automated atlas-based process in Landmark Editor (version 3.6; University of California at Davis). Homologous 3D landmarks (soft-tissue [midline, n = 9; bilateral, n = 10; total, 29] (Supplemental Table 3; Supplemental Figure 1) and internal facial skeleton and mandible [midline, n = 10; bilateral, n = 52; total, 114]) (Supplemental Table 4; Supplemental Figure 2) were identified. To assess measurement error, thresholding and landmarking were performed on a subset of subjects (n = 30) on three occasions with at least 24h between landmarking sessions to avoid memory bias in landmark placement. Landmarks measurement error was considered to be sufficiently low as long as there was no significant difference observed between trials ($p>0.05$, Procrustes ANOVA).

3.2.6 Geometric Morphometrics and Data Analysis

We used Procrustes superimposition to register our sample into a common 3D tangent shape space where the raw coordinate (x, y, z) configurations are aligned to the group centroid, scaled to a common centroid size of one, and rotated to minimize squared-deviation.[183] In this study, we performed a multivariate regression of VAS scores on shape to better parse the influence of our predictors (FATT and M/F VAS scores) on shape compared to Principal Components Analysis (PCA). We can therefore assess the shape variation predicted by our independent variable (FATT and M/F VAS scores), rather than going into the data unbiased (as in PCA). As well, we are able to get similar information as in a PCA; a % shape explained (equivalent to an eigenvalue), a shape vector (equivalent to the eigenvector of a PC), and a regression score (equivalent to the PC score). In other words, from the total shape variation we are parsing the variation associated with our independent variables (FATT and M/F VAS scores), testing for the effect's significance, and then visualizing that as the shape vector's effect on the mean configurations.

To estimate shape changes associated with each continuous variable (FATT, M/F) we performed multivariate regression analysis using the associated VAS scores (FATT and M/F) as independent variables, and soft-tissue or skeletal shape changes (the coordinate data after Procrustes superimposition) as dependent variables, with significance calculated via permutation (1,000 replicates). The resulting regression scores (FATT:shape or M/F:shape) represent the predicted shape outcomes and tell us how much of the total shape variation is explained by our independent variables (FATT VAS or M/F VAS) along with a shape vector that describes the shape changes associated with each continuous variable (FATT VAS and M/F VAS). Following calculation of these regression scores, we looked at possible relationships between FATT:shape and M/F:shape regression scores (dependent variable) and ANB, FATT VAS and M/F VAS (independent variable). For our sample CBCT, this procedure was completed both within sexes, and for all individuals.

To visualize estimated shape vectors, we first constructed an average shape for our population by identifying the individual with the minimum Procrustes distance from the mean and warped this

3D object to the mean configuration. Next, to interpret calculated shape changes for each specific association we applied the shape vectors to the negative and positive extremes (Figure 27A,B) on the “average” face (Figure 27D-G). All statistical analyses were conducted by a single examiner (NY) using *MorphoJ* (version 1.05f) and/or *Landmark Editor* software.

Each assessor rated 8 scans twice during the study. Intraclass correlation coefficient (ICC) was used to test the reliability within the raters using the absolute VAS scores and was completed with SPSS. The statistical significance level was set at $p < 0.05$. (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.).

3.3 Results

3.3.1 Raters

We recruited 108 raters, of which eight were excluded due to high Anxiety Scores (n=3) or incomplete VAS scale scoring (n=5) leaving a total of 100 participants (Table 4). A missing “mark” on the VAS evaluation of FATT and M/F was an indication that the assessor did not follow the order of the presented CBCT facial images; therefore, an assessment could have been attributed to the wrong CBCT image.

The majority of the raters in the study were White Canadians (53%) with bachelor’s degrees (81%) with an average age of 30 years (age range 19-65 years). Sixty-one raters were students in their 1st year in dental school and 39 had varying backgrounds. The mean±SD trait anxiety was 31.3±8.4 and 34.4±8.2 for the State and Trait Anxiety test parts of the questionnaire, respectively, indicating that most of the participants did not show excessive anxiety. There was moderate to good agreement within the raters for FATT VAS scores (R = 0.728, 95%CI = 0.668 to 0.763, $p < 0.001$). Similarly, there was moderate to good agreement within the raters for the M/F VAS scores (R= 0.765, 95%CI = 0.730 to 0.796, $p < 0.001$).

3.3.2 Facial Attractiveness

3.3.2.1 Facial Attractiveness VAS scores (FATT) and associated shape changes (FATT:shape)

A significant positive association ($R^2 = 0.46$, b=0.0015, P=0.0491) was observed between FATT VAS and external facial shape (FATT:shape) (Figure 26), with a predicted value of 4.4%. A significant relationship was also observed for FATT and the skeletal data shape data (R^2 =0.477, b=0.0015, P=0.0296). This result was largely driven by females in whom a stronger correlation was observed (R^2 = 0.67, b=0.0027, P=0.006), with a predicted shape change of 11.51% (Figure 26) compared to males (R^2= 0.56, b=0.0014, P=0.4434)(Supplemental Figure 3).

The coefficient of determination (R^2) value of the correlations of independent variables (ANB, FATT and M/F) and shape (FATT:shape and M/F:shape) explains how well the estimated shape vector predicts the individual's shape from the independent value (ANB, VAS). This should not be confused with the amount of variation explained (predicted value %). Here, for example, the amount of shape variation explained by FATT for all individuals is small as per our predicted value (4.4%), but larger in our female CBCT population (11.51%).

In this study, changes in the landmark position using shape vectors were observed in order to evaluate shape differences. Analysis of the shape vector plots revealed that FATT in this sample is associated with more anterior and inferior displacements of gnathion and pogonion (landmark 8 and 9 - Figure 27B) (R^2=0.46, b=0.0015, P= 0.049). As well, the lower lip (landmark 6 - Figure 27A, B) was displaced superiorly (i.e., a shorter lower lip) with a higher FATT score. Upward displacement of the right and left chelion (corners of the mouth) (landmark 24 and 25 - Figure 27A) had a positive association on the rating of attractiveness. A decrease in the philtrum projection (landmark 22 and 23 - Figure 27B) and therefore lip projection was also associated with higher ratings for all subjects. We observe a straight profile with a more prominent chin and retrusive and thinner lips for the highest rated FATT face (Figure 27F,G). For the average face morphed to be the least attractive, we find a convex profile with protrusive lips and a retrusive chin (Figure 27D,E). As well, we found that the shape changes are mostly occurring in the lower third of the face (Supplemental Video 2, Supplemental Video 3).

For the hard tissue shape changes associated with FATT, the pogonion and gnathion were found to be displaced anteriorly just like their soft-tissue counterpart (R^2 = 0.477, b=0.0015, P=0.0296). However, there was a superior displacement of the hard tissue chin (landmarks 61 and 62 - Supplemental Figure 4B) as compared to the soft tissue landmarks (displaced more inferiorly). Furthermore, a mandible that has a ramus that is displaced posteriorly was associated with increased scoring of FATT for all subjects (landmark 64,78,80 - Supplemental Figure 4B).

3.3.2.2 ANB angle

Because FATT appeared to be driven by changes in jaw position, we assessed how well FATT:shape correlated with ANB. We found a significant association between the ANB angle and FATT:shape for both the soft-tissue (R^2 = 0.449, b=-0.006, <0.0001) (Figure 28) and skeletal data (R^2 = 0.2793, b=-0.005, p=0.0012) (Figure 28). As the ANB value increased, statistically significant shape changes were negatively rated (p <.0001) with a predicted value of 44.9%, i.e., ANB predicts 44.9% of shape change. Indeed, as the severity of skeletal sagittal Class II discrepancy increased, as measured by ANB, the attractiveness score decreased (Figure 28).

3.3.3 Sexual Dimorphism (Masculinity and Femininity)

The linear regression for relative masculinity and femininity (M/F) and M/F shape variation (M/F:shape) was significant and positive (R^2= 0.4611, b=0.0009, p=0.0175) (Figure 29) with a predicted value of 5.15%. Looking at the skeletal data, there was a positive association between M/F and M/F shape (R^2= 0.4308, b=0.0008, P=0.0158). A higher M/F score indicates more feminine facial features while a lower score indicates more masculine facial features. Interestingly, we observed that female subjects were rated as having more feminine facial features, while males were rated as having masculine features (Supplemental Figure 5).

Prominent cheeks (landmark 27 and 26 - Figure 30A) and posterior displacement of the tip of the nose (landmark 2 - Figure 30B) and chin (landmark 8 and 9 - Figure 30B) were significantly associated with a more feminine facial appearance ($R^{2=}$0.62, b=0.0013, P=0.192). As well, an inferior-posterior displacement of the lower lip was also rated as being more feminine-like (landmark 6 - Figure 30B,C). These 3D shape changes of femininity and masculinity are illustrated in the morphed faces in Figure 30(D-G), and in Supplemental Video 4.

3.4 Discussion

In this study, we sought to characterize the 3D shape correlates of FATT and sexual dimorphism from CBCT scans in subjects with varying degrees of SSD. We hypothesized that individuals with SSD possess defined 3D facial characteristics of attractiveness and sexual dimorphism and we predicted that the maxillary-mandibular skeletal relationship (ANB) is a significant predictor of observable FATT. We report three key findings: 1. The relative anteroinferior position of the chin is one of the most important shape related to FATT; 2. Balanced maxillary-mandibular skeletal relationships (ANB of 0° to 3.6°) is a significant predictor of FATT and; 3. Prominent cheeks and posterior displacement of the tip of the nose and chin were associated with a more feminine facial appearance.

In contrast to most studies that used linear and angular measurements to assess FATT, the current study analyzed the entire face in 3D for visualization of detailed morphological shape variations related to attractiveness or sexual dimorphism.[190] Our study therefore represented one of the first in the analysis of FATT and SD at the 3D level and generated a number of new and contrasting insights that are mainly related to the lower third of the face, in addition to confirmatory findings consistent with current literature.

3.4.1 Correlates of Facial Attractiveness in the Lower Facial Thirds

The lower face has conventionally been considered a key element of facial beauty, especially the morphology of the chin and lips.[114,191,192] The shape of the chin has been shown to provide harmony, character and personality to a face.[98,114,191,193-195] In general, straight profiles are considered more attractive than convex or concave profiles, while a chin located within the lower third boundary of the lower face and sagittal central fifth is considered more appealing.[87-89,196]

Few studies on facial esthetics, however, have analyzed the relationship between the sagittal skeletal discrepancy (as measured by ANB values) and FATT; the few that did showed no significant relationship between FATT and ANB values.[197,198] However, our study showed a strong relationship between the soft tissue esthetics of the lower face and the SSD. Indeed, attractiveness was affected by a relative forward positioning of the lower jaw towards a normal skeletal sagittal relationship, as reflected by a decrease in ANB values and a displacement of the hard tissue and soft tissue pogonion anteriorly.[17,199] We confirmed that a protrusive chin or *progenia* associated with a straight profile is strongly related with FATT in all subjects. Similar to the findings of Naini et al. looking at the impact of chin protrusion and retrusion on FATT, our most attractive morphed face (Figure 27G) shows a chin that is coincident with the *zero degree meridian* (a vertical line perpendicular to the Frankfort Horizontal plane and dropped from soft tissue Nasion).[98,101]

Differences between the sexes exist, however, in terms of the characteristics of the chin.[200] In females, an oval shaped facial line and a slightly convex profile has been considered beautiful and balanced.[174,201] In contrast, a straight profile with a rather dominant and broad chin has been deemed esthetic in males.[15,75,194,202,203] Interestingly, our study did not show an important role of the chin in sexual dimorphism as previously found.[178,191] We did find that a retrusive chin is associated with femininity, although the changes were smaller relative to the displacement of the nose.

Variations in lip protrusion and vermillion height appears to be an important secondary contributor of FATT and SD. In general, an upper lip to lower lip ratio of 1:2[13,93,128,204] and a prominent upper lip are suggested to be most attractive and related with femininity.[18,186,205,206] In contrast, we found that a reduced lower lip height and retrusive upper lip were associated with higher ratings of FATT. For profile esthetics, it is important to consider the balance of the lips relative to the nose and chin.[93,114] In convex profiles for example, the lips tend to be fuller and the chin more retrusive.[30] Since most of our sample subjects had convex profiles, the rating of facial beauty may have been influenced towards a straight profile with retrusive lips and prominent chin.[207,208] As well, variations in lip morphology and size have a significant ethnic basis; African populations have a greater vermillion height and protrusive lips than Caucasians or Orientals.[123,124,130,209,210] Lip preferences also depend on cultural differences with Caucasians preferring smaller lips than non-Caucasians.[123] Some of the differences in our findings when compared to others could perhaps be related to the fact that a large proportion of the CBCT scans in our study were non-Caucasian, while our assessors were mainly Caucasian (53%). Nevertheless, we found that lower lip protrusion was associated to femininity, consistent with other studies where it has been suggested that women have more prominent lips than men.[123,125,182,208] Interestingly, upwardly positioned lip corners of the mouth, suggestive of a slight *commissure* smile[211] at rest position, were associated with increased ratings of attractiveness. Since the subjects were asked to rest and not to smile for scans, it is possible that this smile was related with their lip morphology (static) and not with an action (muscle contraction and movement). A smile has often been linked with FATT[28,212,213] and positive judgments of trustworthiness;[214] it is not surprising, therefore, that our assessors rated an upward displacement of the corners of the mouth as being more attractive.

3.4.2 Assessors and External Validity

Most investigations on attractiveness used highly appealing females (models, actress etc.) as subjects for assessment of FATT in contrast to the use of an orthodontic patient population.[30,142,215] In the current study, laypeople assessors were recruited as they were likely to represent the "average" general population with regard to their educational background and cultural influences in their perception and assessment of attractiveness compared to the possible biased attitudes of professionals.[123,202,216,217] Assessors of 18 years and older with no age restriction were also chosen to best represent our patient pool, especially since there has been an increase in older patients seeking orthognathic surgery.[218] Most importantly, we did not seek to examine or eliminate the impact of ethnicity or age in either the subject population that was scanned or in the assessor group since studies have shown that esthetic judgements seemed to be similar across different cultural backgrounds.[36,202,216] As tested in our pilot study, the assessors had an adequate amount of time (20s) to view and rate each image. As well, according to Stróżak et al., it takes less than a second to for individuals to evaluate FATT.[219]

3.4.3 Female Attractiveness and Sexual Dimorphism

Female faces reportedly have specific facial traits - larger eyes, oval shaped faces, prominent cheeks and lips, and small noses and chins.[5,13,76,77,216] In contrast, men tend to have square-shape faces and jaws, wide and pronounced nose and chin, thin lips, wide mouth and less prominent cheeks.[152] We observed that female subjects were rated as having more feminine facial features, while males were rated as having masculine features indicating that there are distinct facial features of sexual dimorphism even when extrinsic factors are eliminated (Supplemental Figure 5). This is in accordance with other studies that found that people were remarkably accurate (75 to 98%) at determining whether 3D faces are male or female, even when cues from hairstyle, makeup, and facial hair are minimised.[178,179,220,221] The stronger relationship of FATT in females compared to male subjects suggests that female faces were somewhat rated as being more attractive than men (Supplemental Figure 4). This supports the hypothesis that facial femininity is associated with higher attractiveness according to male and female perception.[193,201,202,222] It could be due to our assessor population being prominent in female raters (65%) since it has been shown that women are about equally aroused when viewing men or women while men are only aroused by women.[223] We also found that the cheeks and the nose are important in relation to sexual dimorphism. Traditionally, women have been found to have greater thickness and roundness of the cheeks than men.[13,23,74,77,224,225] Few studies have analyzed the 3D morphological traits of the cheek - our study corroborated the one report that showed that enlarged and rounded cheeks (inferior and lateral displacement) were highly associated with a more feminine facial appearance.[182] This could be explained by the buccinator muscles being more developed in females since it has been speculated that they smile more often than males.[226] Furthermore, a retrusive nose shape was associated with increased femininity in our study. This is in line with the hypothesis that the largest anatomical SD in the human face is represented by the protuberance of the nose; with protruded noses rated as more masculine, and retrusive noses rated as more feminine.[178-182] In agreement with multiple studies on SD, it seems that manipulating the shape of the nose, cheeks, and, to a lesser extent, the chin, can have significant effects on the apparent masculinity and femininity of the face.[75,178,194,202,203,227]

Taken altogether, our study provides data that offers insight and guidance in the orthodontic and surgical treatment planning and management of patients with SSD. Shape transformations using interactive 3D morphed faces allows the visualization of changes that are often seen in two dimensions with silhouettes or photographs. Therefore, we deliver a more realistic approach to the evaluation of a face in 3D and convey an excellent framework for further investigations of FATT and SD. However, CBCT soft-tissue images of the faces has the limitation of being proxies and may possibly be an inaccurate representation. The use of three-dimensional photogrammetry could be a solution for this limitation. Future studies should take into account the ethnicity of the sample and assessors, addition of more landmarks, inclusion of skeletal Class III patients.

3.5 Conclusion

Our findings demonstrate 3D shape correlates of FATT and SD in both the visible face and the underlying skeleton. Our findings support the idea that balanced skeletal Class I (ANB value of 0° to 3.6°) jaw associations are the most consistent predictor of perceived attractiveness. They confirm the significance of chin prominence as a major driver of FATT. As well, prominent cheeks and posterior displacement of the tip of the nose and chin were significantly associated with a more feminine facial appearance.

The impact of our study lies in the quantification of 3D correlates of facial beauty and sexual dimorphism that can be formulated as a standardized and objective guide for the movements needed during surgeries involving the jaws and face. Our findings therefore provide guidance in the orthodontic/surgical treatment planning of patients with SSD, with potential to help predict the amount of surgical advancement needed to improve FATT in individual feminine and masculine faces. Accordingly, our outcomes can be used towards helping these patients improve their facial esthetics and therefore their quality of life and well-being.

3.6 Compliance with Ethical Standards

3.6.1 Conflict of Interest

All authors declare that they have no conflict of interest.

3.6.2 Funding

This study received no funding.

3.6.3 Ethical Approvals

The protocol was approved by the Research Ethics Boards of both the University of Toronto (REB #36419) and University of California San Francisco (IRB #11-06996) (Appendix A)

3.6.4 Informed Consent and Confidentiality

Participants were given a verbal and written informed consent (Appendix B) acknowledging the receipt of information and confirming their willingness to participate in the study. All information was collected and analyzed confidentially in accordance with the University of Toronto, Faculty of Dentistry’s Privacy Policy (Appendix B). Participation was voluntary, and the participants had the right to withdraw from the study for any reason at any time.

3.7 Manuscript Table

Table 4. Raters Description

Variables	**Number of Participants**		
Raters	100		
Males	35		
Females	65		
Average age	30.5 yearrs old		
Minimum age	19 years old		
Maximum age	65 years old		
Ethnicity	50 Canadians	2 French	23 Other
	7 Chinese	3 Polish	
	11 South Asian	3 Filipino	
Race	53 White 14 South Asian 14 East Asian (Chinese, Korean)	2 Black 6 West Asian 4 Arab	4 Latin American 3 others
Schooling Degree	6 High School Degree	11 College	81 University or bachelor's degree 2 Degree Above Bachelor's Degree
Background	61 1st year dental students 39 Other		

3.8 Manuscript Figures

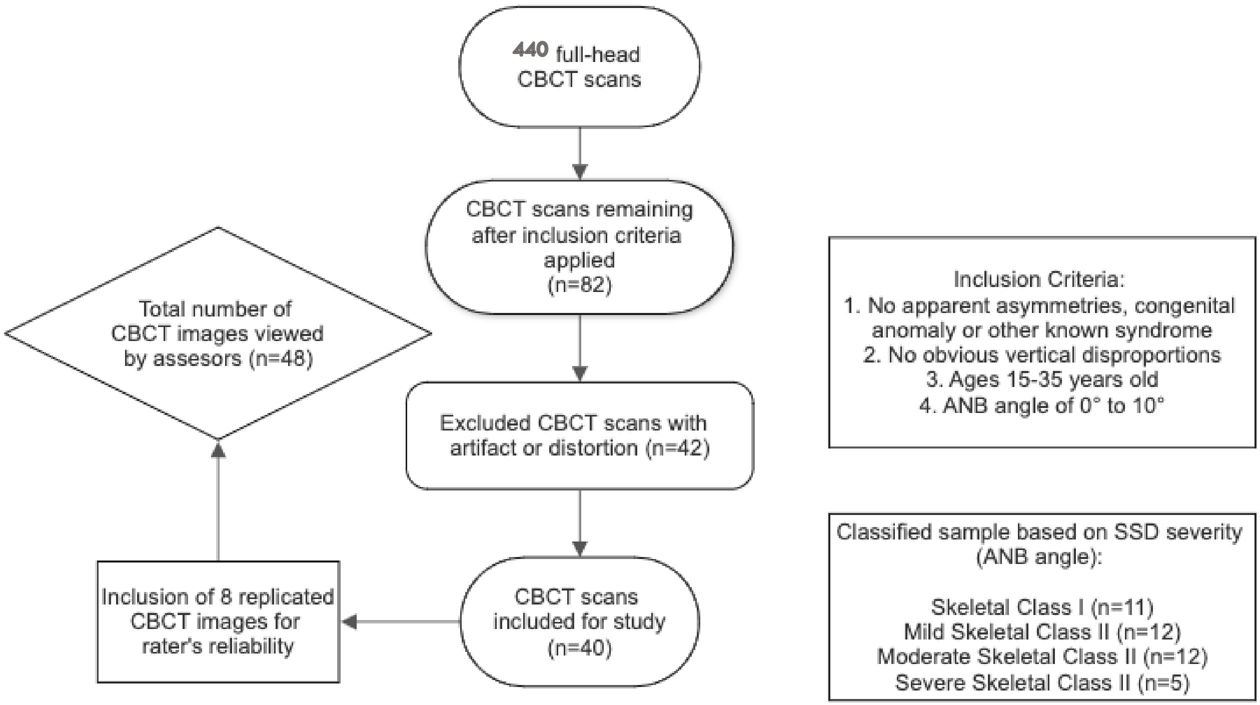


Figure 25. Selection of the CBCT scans models.

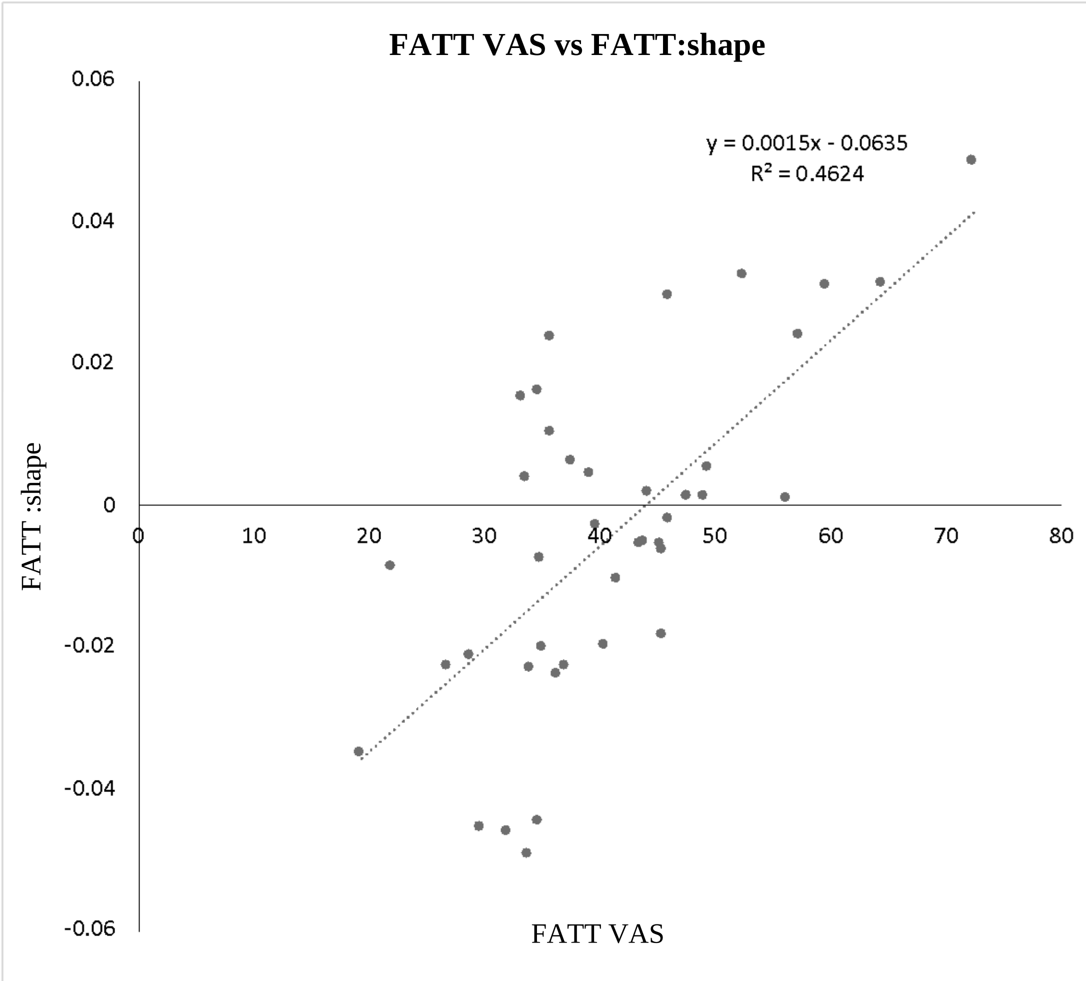


Figure 26. Facial Attractiveness (FATT) in relation to FATT:shape for all subjects. An increased FATT VAS score indicates a more attractive rating and is therefore associated with more attractive shape changes. Our dependent variable (y-axis) is the regression score of our independent variable (FATT VAS) on shape (Procrustes coordinates). It illustrates how much of shape variation is explained or predicted by our independent variable. The higher the regression score (0.06), the more attractive associated shape changes. Our independant variable (x-axis) is the VAS scores of FATT ranging from 0 to 100. Each dot on this graph represents an individual in our CBCT sample, and therefore contains a "load" of shape coordinates variations which can be viewed in Figure 27. The coefficient of determination (R^2) represents how well the estimated vector predicts the individual's shape from the independent variable (FATT VAS).

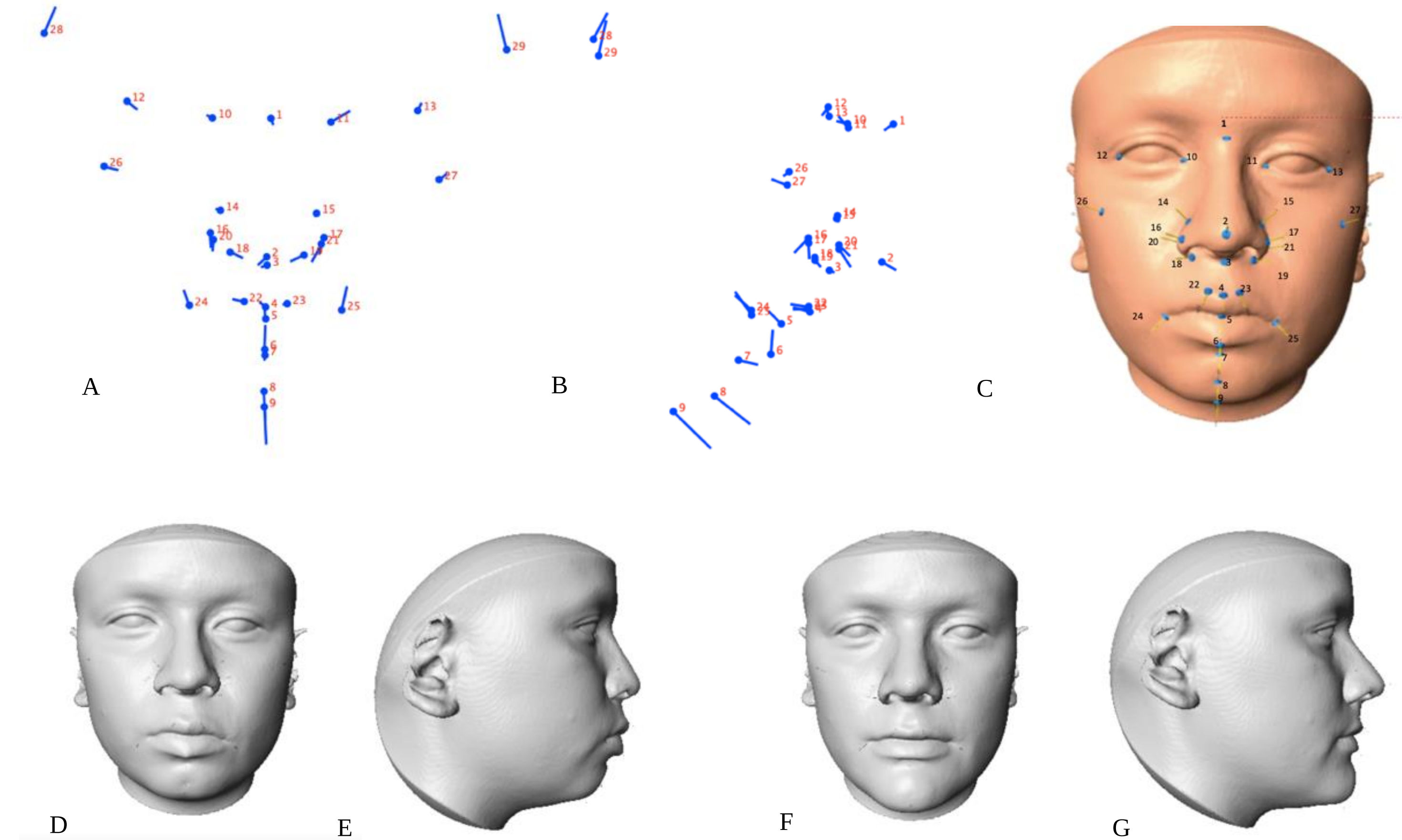


Figure 27. (A,B) Vectors of shape changes (FATT:shape) associated with FATT VAS score (all subjects) in MorphoJ software. The blue dots indicate the average position of the landmarks and the blue lines indicate the direction of displacement of the landmarks in relation to FATT. The longer the line, the more displacement of the landmark according to ratings of FATT. A) Frontal view B) Profile view C) Landmarks. (D,E,F,G) Images of the average face in the sample morphed using the displacement vectors (blue lines in A and B) to show the extremes for less (D, E) and more (F,G) attractive faces. We observe a straight profile with a prominent chin, a decrease lower lip vermillion, a reduced lip projection and an upward displacement of the commissure of the mouth in more attractive faces (F,G).

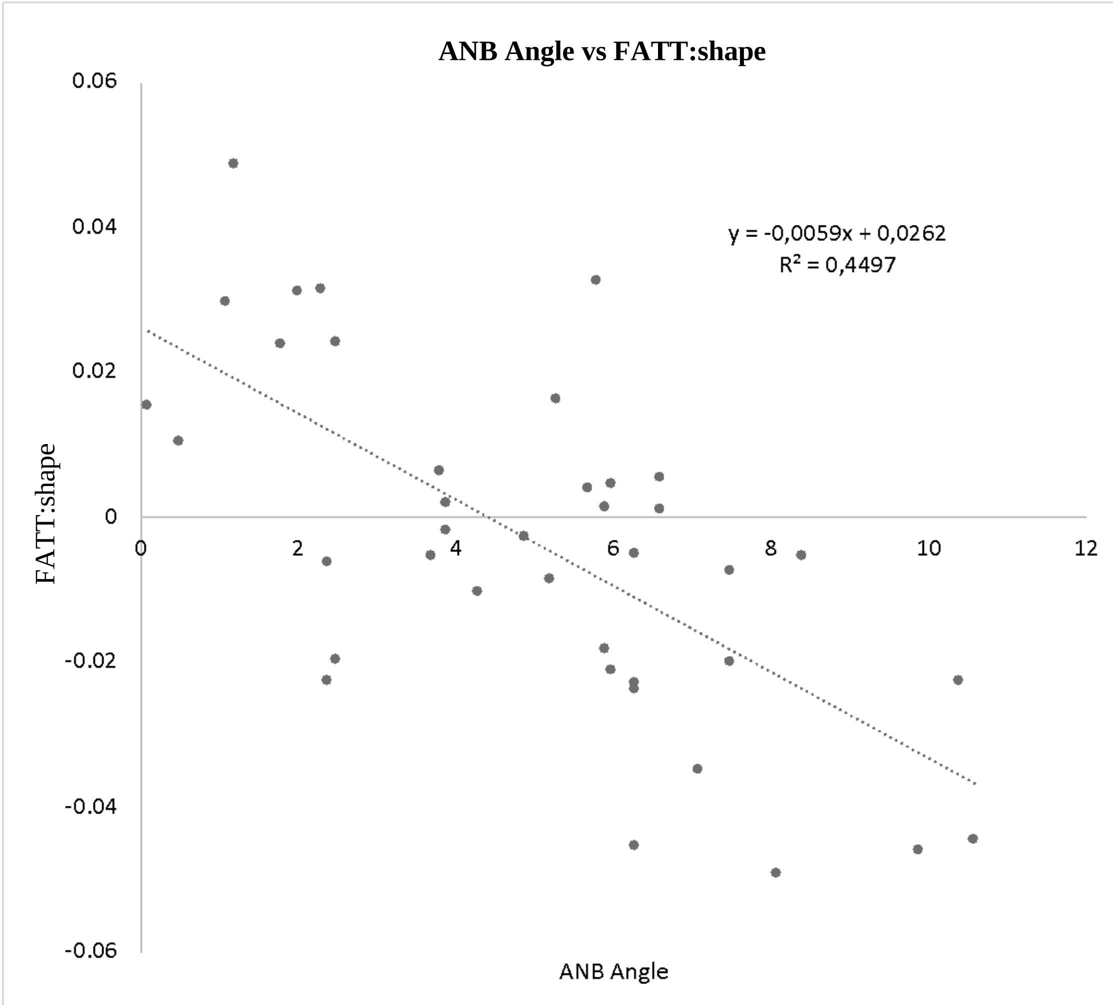


Figure 28. Sagittal skeletal Class II discrepancy and associated shape changes (ANB in relation to FATT:shape). As the sagittal skeletal discrepancy severity increases (increased ANB), FATT decreases.

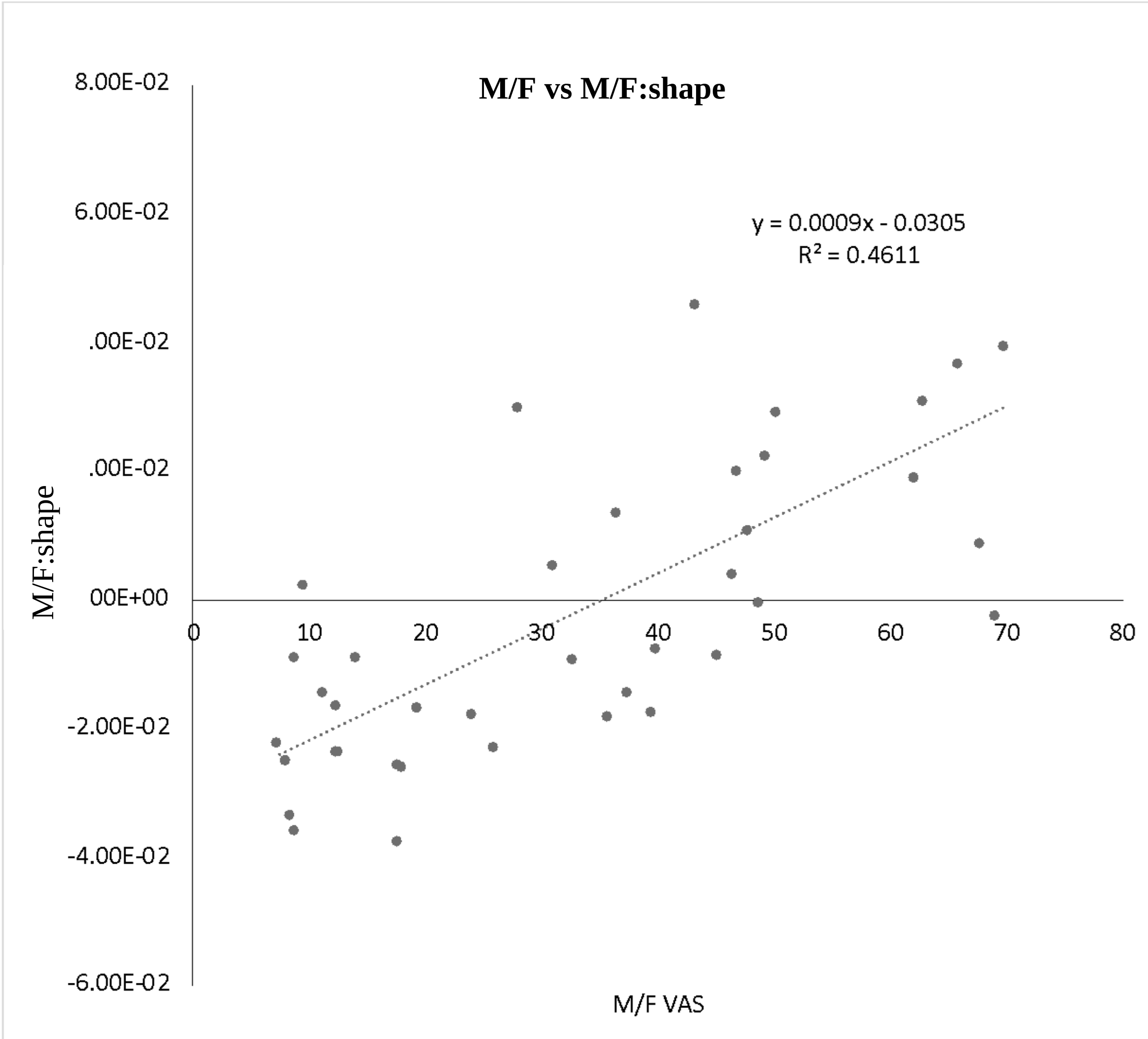


Figure 29. M/F VAS Score vs M/F:shape. Since our independant variable (x-axis) represents the M/F VAS scores ranging from 0 to 100, an increased M/F VAS score indicates a more feminine rating and is therefore associated with more feminine shape changes. Each dot on this graph represents an individual in our CBCT sample, and therefore contains a “load” of shape coordinates variations for masculinity and femininity which can be viewed in Figure 30.

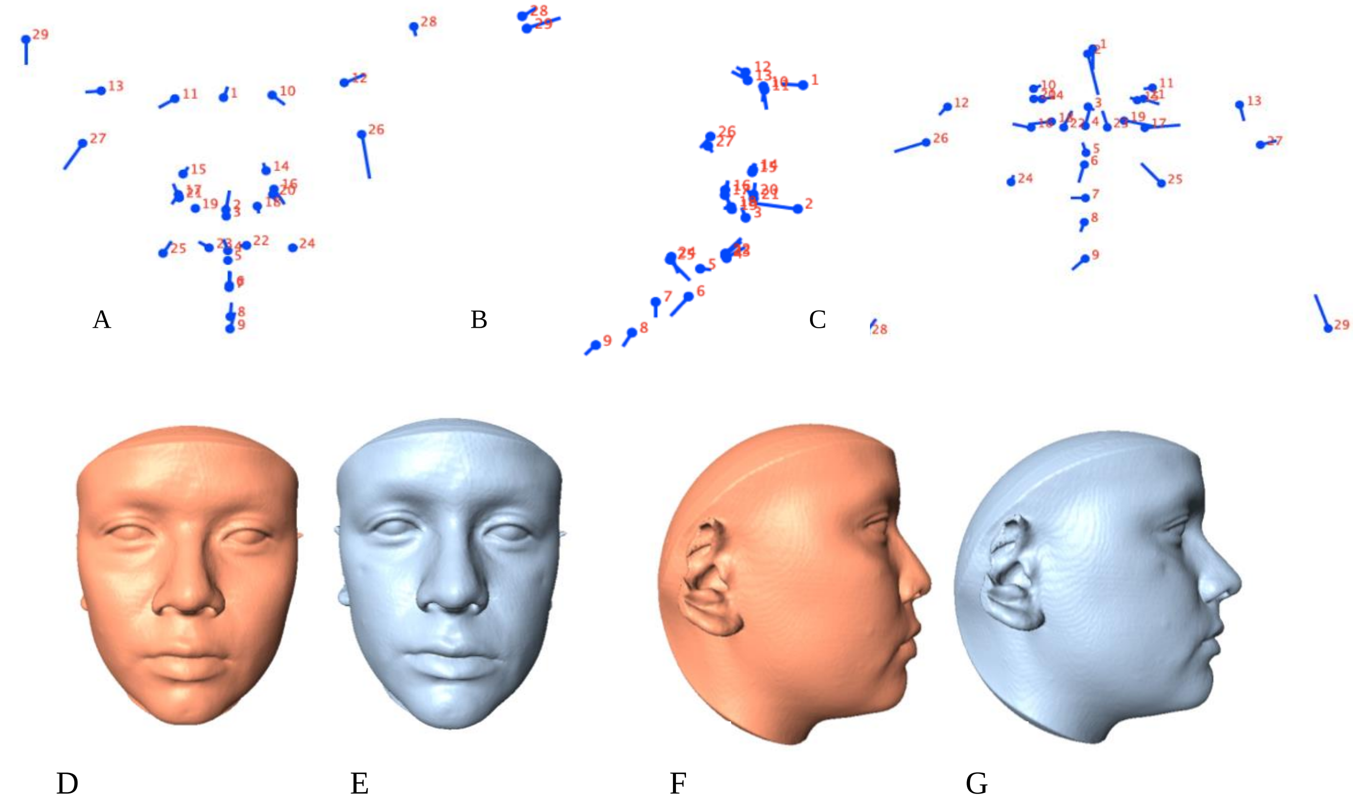
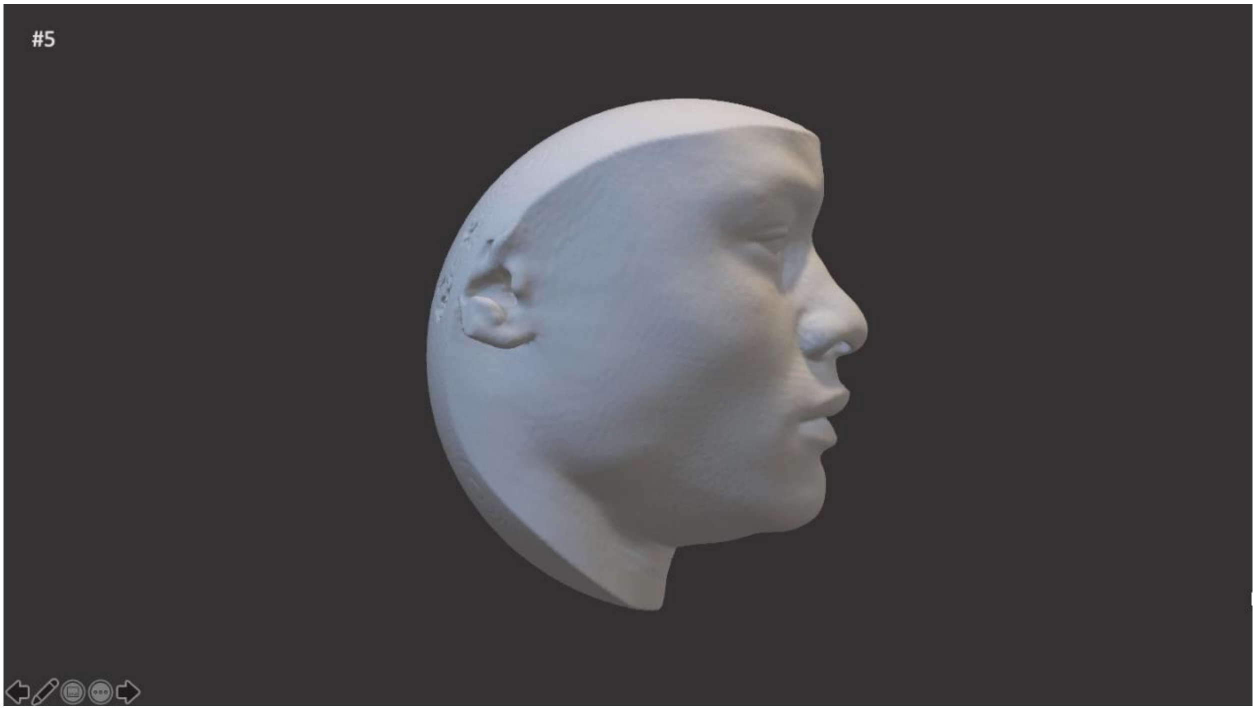


Figure 30. (A,B,C) Landmark changes related to M/F ratings. A) Frontal view, B) Profile view and C) Transverse view. The more displacement (blue line), the more feminine-rated the landmark displacement is. (D,E,F,G) Images of the average face in our sample morphed to show shape changes of femininity (in red, D and F) and of masculinity (in blue, E and G). We observe a smaller nose and protrusive round cheeks in the feminine face (D and F).

3.9 Supplemental Material



Supplemental Video 1. Example of video clip viewed by assessors.

Supplemental Table 1. Selection and Distribution of Faces.

Class I Faces (ANB of 0° to <3.6°)	Class II Mild (ANB of ≥3.6° to <6°)	Moderate class II (ANB of ≥6° to < 8°)	Severe class II (ANB ≥ 8°)	Replicated Faces (2 faces of each category)	Total Faces
11	12	12	5	8	48

Supplemental Table 2. Demographic Description of CBCT participants.

CBCT Sample		
Subjects	40	
Males	19	
Females	21	
Average age	21 yrs. Old	
Min age	15	
Max age	35	
Median Age	21	
Ethnicity	9 Caucasian	2 Chinese
	3 Hispanic	22 Other
	4 Black	

Supplemental Table 3. Digitized Facial Soft Tissue Landmark (n=29). Illustrated in Supplemental Figure 1.

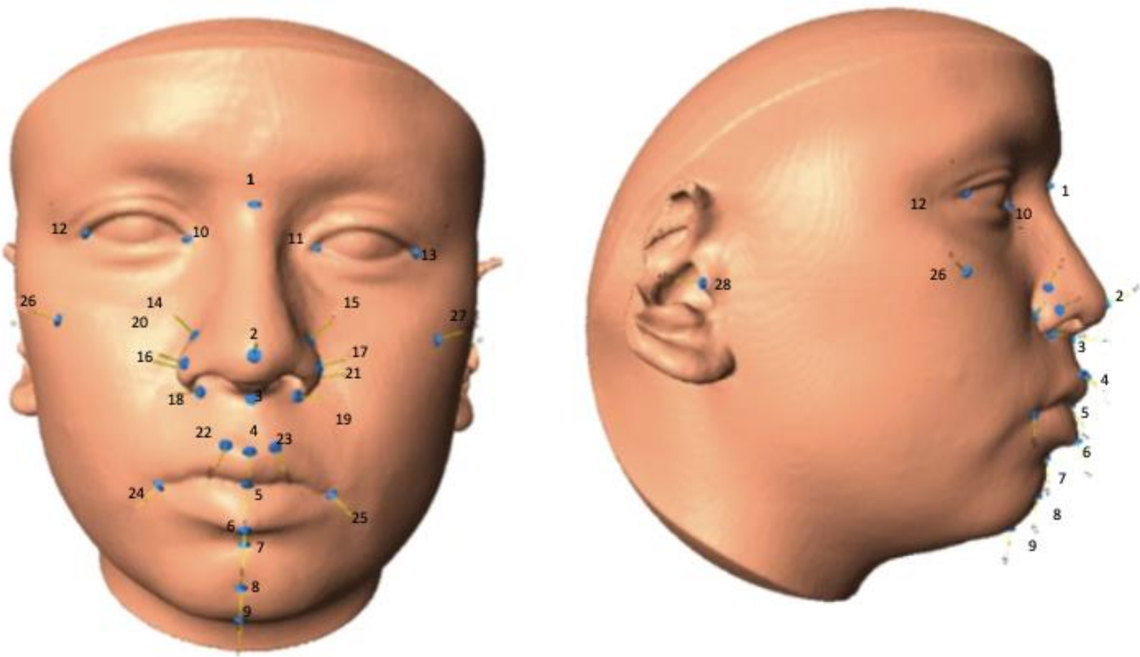
Landmark Name	Landmark Label (#)	Description
Glabella (g)	1	The most prominent midline between eyebrows la
Pronasale (prn)	2	The most protruded point of the nasal tip (tip of nose)
Subnasale (sn)	3	The deepest midline point where the base of the nasal columella meets the upper lip
Labiale Superius (ls)	4	The midpoint of the vermilion line of the upper lip
Stomion (sto)	5	The midline point of contact between the upper and lower lip
Labiale Inferius (li)	6	The midpoint of the lower vermilion line
Sublabiale (sl)	7	The midpoint of the labiomental sulcus
Pogonion (pog)	8	The most anterior midpoint of the chin
Gnathion (gn)	9	The lowest median landmark on the soft tissue chin contour
Endocanthion (en)	10 & 11	The inner commissure of each eye fissure
Exocanthion (ex)	12 & 13	The outer commissure of each eye fissure
Superior Alare	14 & 15	The most superior point at the junction between alar wing and face
Alare (al)	16 & 17	The most lateral point on each alar contour

Subalare (sbal)	18 & 19	Edge of nasal ala where cartilage of the nose inserts the tissue above the upper lip
Alare Curvature Point (ac)	20 & 21	The most lateral point on the nasal alar crest
Christa Philtri (cph)	22 & 23	The point where the philtral ridges meet the vermillion border of the upper lip
Chelion (ch)	24 & 25	The point located at each labial commissure
Cheek (chk)	26 & 27	Cheeks
Tragion (t)	28 & 29	The most superior aspect of the tragus where it abuts the face

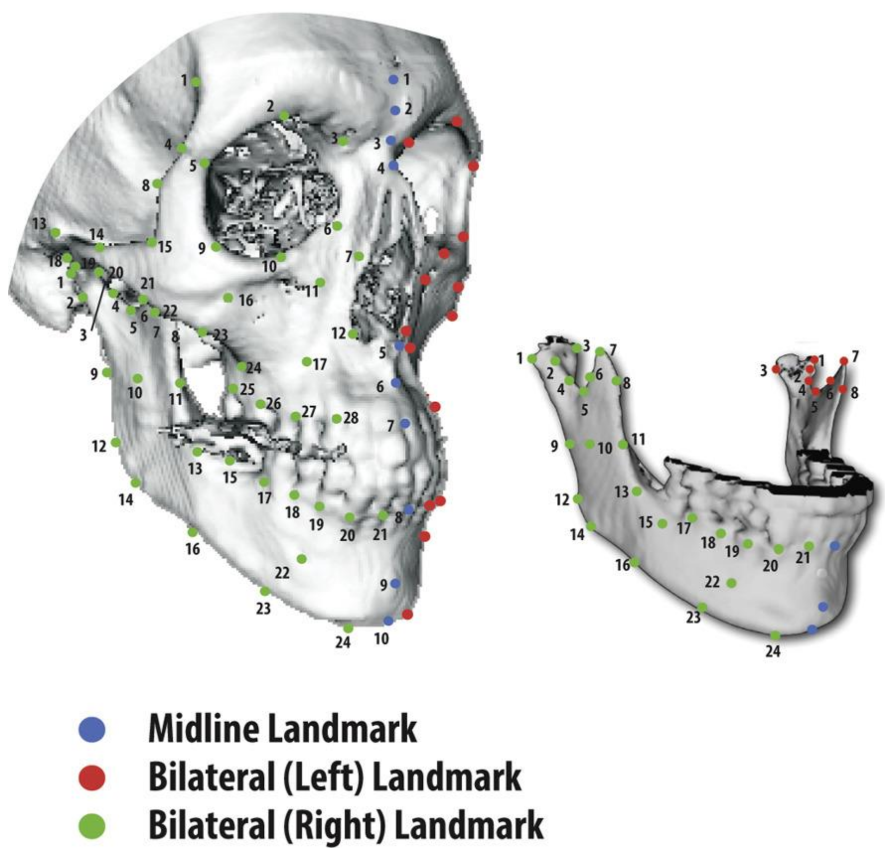
Supplemental Table 4. Digitized Skeletal (Hard Tissue) Landmark (n=114). Illustrated in Supplemental Figure 2.

Type	Region	#	Description
Bilateral	Cranium	1	Frontotemporale
Bilateral	Cranium	2	Superior midpoint of the orbit
Bilateral	Cranium	3	Supero-medial margin of the orbit
Bilateral	Cranium	4	Frontomalare temporale
Bilateral	Cranium	5	Ectochonchion
Bilateral	Cranium	6	Infero-medial margin of the orbit
Bilateral	Cranium	7	Lateral margin of the nasal aperture
Bilateral	Cranium	8	Supero-most point posterior to Frontomalare temporale
Bilateral	Cranium	9	Infero-lateral margin of the orbit
Bilateral	Cranium	10	Inferior midpoint of the orbit
Bilateral	Cranium	11	Infraorbital foramen
Bilateral	Cranium	12	Alare
Bilateral	Cranium	13	Location above auricular where temporal portion of zygomatic meets cranium
Bilateral	Cranium	14	Zygonion
Bilateral	Cranium	15	Jugal point of zygomatic
Bilateral	Cranium	16	Midpoint between (10) and (23)
Bilateral	Cranium	17	Midpoint between (12) and (27)
Bilateral	Cranium	18	Auricular
Bilateral	Cranium	19	Zygomatic just anterior to condylar junction
Bilateral	Cranium	20	Midpoint between (19) and (21)
Bilateral	Cranium	21	Inferor of zygomatic directly below (15)
Bilateral	Cranium	22	Zygomaxillare
Bilateral	Cranium	23	Midpoint between (22) and (24)
Bilateral	Cranium	24	Inferolateral juncture of zygomatic with maxilla
Bilateral	Cranium	25	Alveolar above M2
Bilateral	Cranium	26	Alveolar above M1
Bilateral	Cranium	27	Alveolar between premolars
Bilateral	Cranium	28	Alveolar above canine

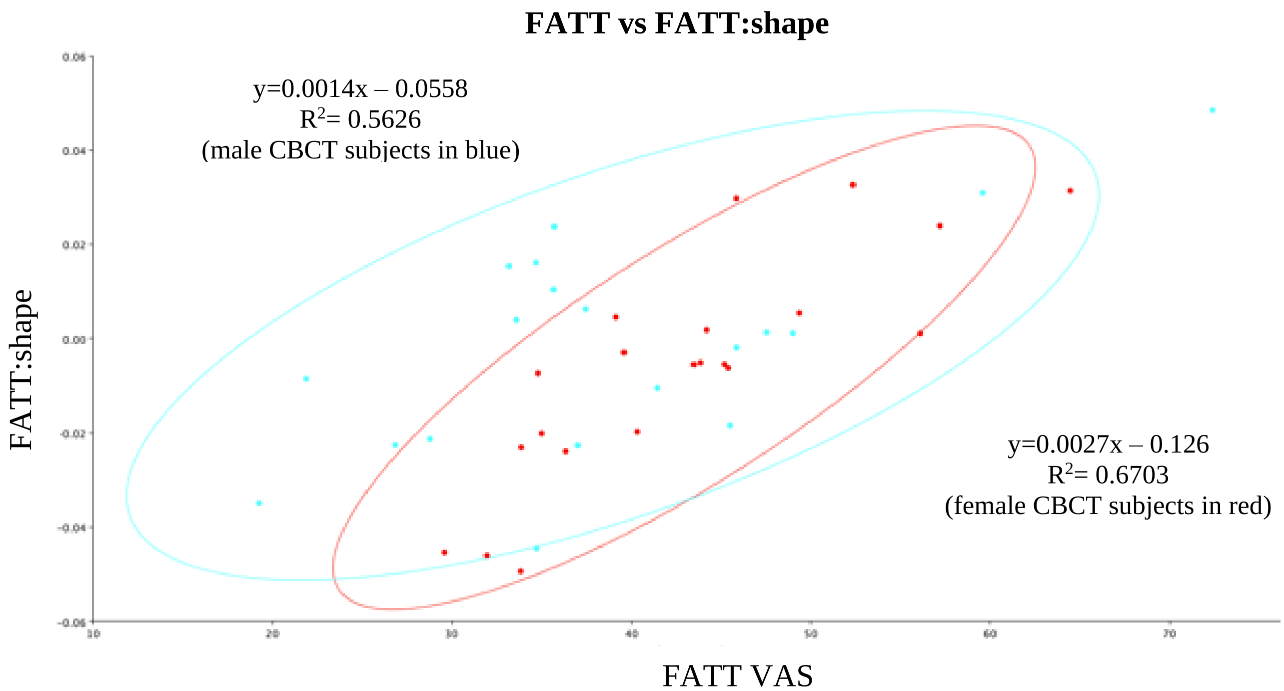
Bilateral	Mandible	1	Condylion laterale
Bilateral	Mandible	2	Junction of ramus at condyle (anterior)
Bilateral	Mandible	3	Condylion mediale
Bilateral	Mandible	4	Midpoint between (2) and (5)
Bilateral	Mandible	5	Mandibular notch
Bilateral	Mandible	6	Midpoint between (5) and (7)
Bilateral	Mandible	7	Coronion
Bilateral	Mandible	8	Anterior complement to (6)
Bilateral	Mandible	9	Midpoint betwwen (1) and (12)
Bilateral	Mandible	10	Midpoint between (9) and (11)
Bilateral	Mandible	11	Midpoint between (8) and (13)
Bilateral	Mandible	12	Gonion
Bilateral	Mandible	13	Distal extent of anterior edge of ramus
Bilateral	Mandible	14	Postero-most inferior edge of mandible
Bilateral	Mandible	15	Alveolar below M2
Bilateral	Mandible	16	Lateral extent below (13)
Bilateral	Mandible	17	Alveolar below M1
Bilateral	Mandible	18	Alveolar below P4
Bilateral	Mandible	19	Alveolar below P3
Bilateral	Mandible	20	Laterale infradentale
Bilateral	Mandible	21	Alveolar below lateral and medial incisor
Bilateral	Mandible	22	Mental foramen
Bilateral	Mandible	23	Lateral extent of mandible below (22)
Bilateral	Mandible	24	Lateral extent of the mental eminence
Midline	Cranium	1	Depression above glabella on frontal at top of browridge
Midline	Cranium	2	Glabella
Midline	Cranium	3	Nasion
Midline	Cranium	4	Distal extent of nasal
Midline	Cranium	5	Akanthion
Midline	Cranium	6	Midpoint between akanthion and prosthion
Midline	Cranium	7	Prosthion
Midline	Mandible	8	Infradentale
Midline	Mandible	9	Pogonion
Midline	Mandible	10	Gnathion



Supplemental Figure 1. Soft-Tissue Landmarks.



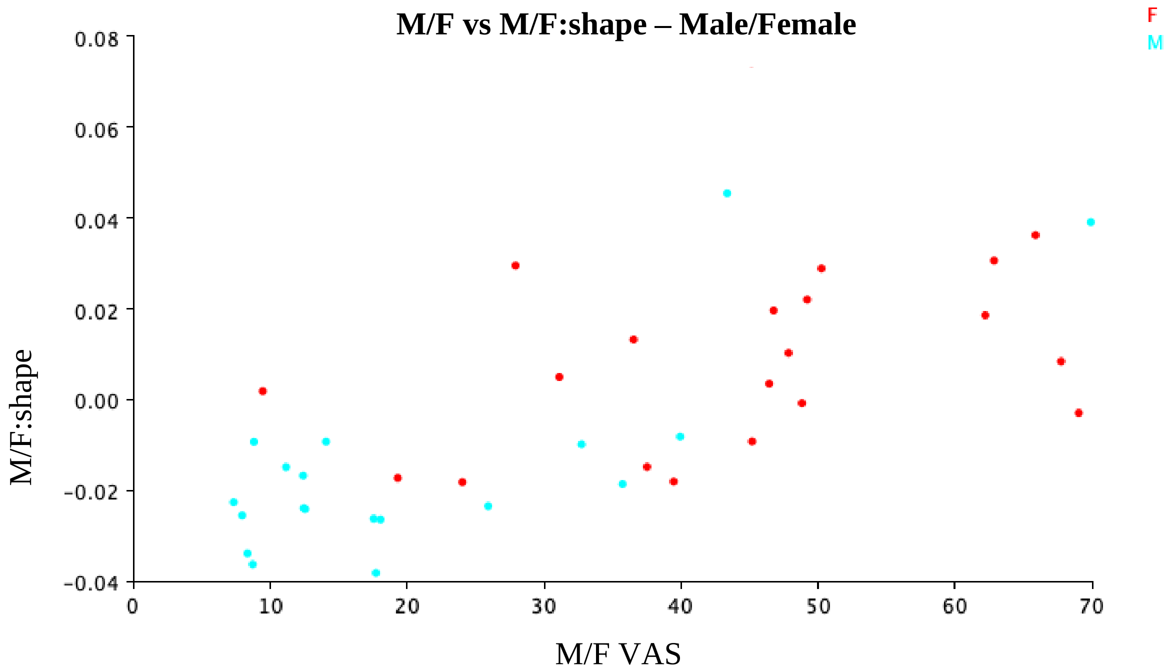
Supplemental Figure 2. Skeletal Landmarks.



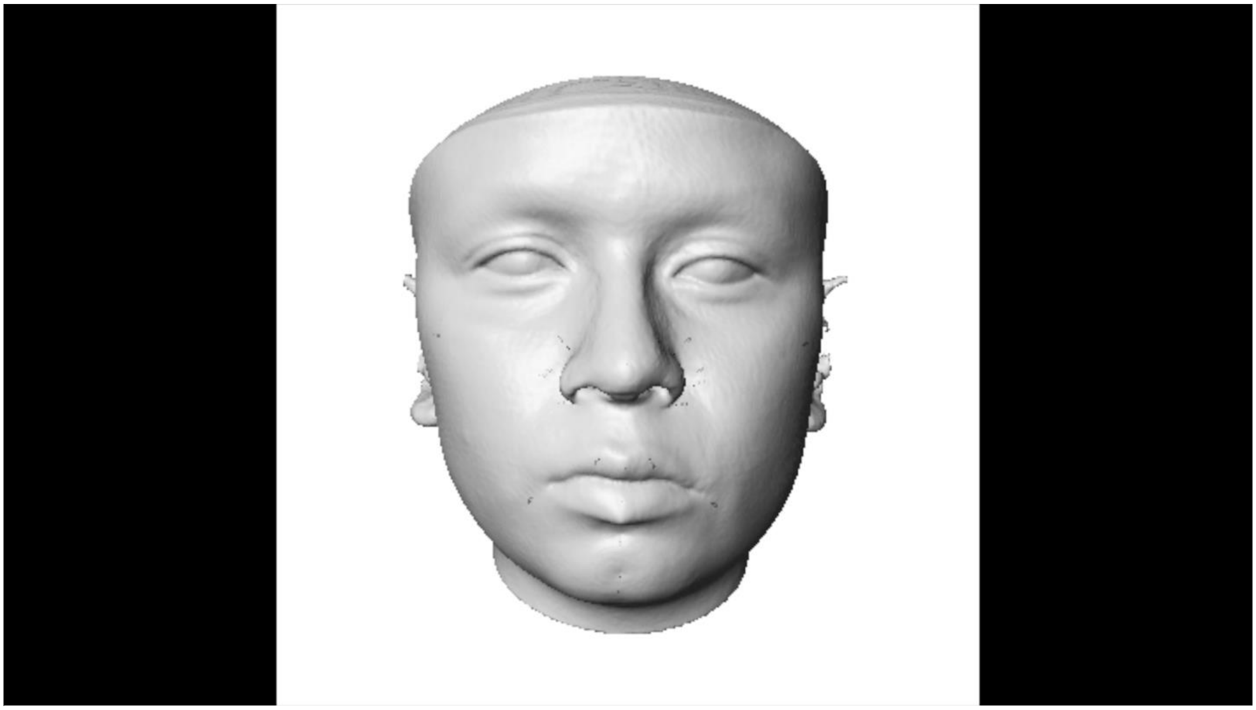
Supplemental Figure 3. Facial Attractiveness VAS (FATT) in relation to FATT:shape for Female (Red, n=21) and Male (Blue, n=19) CBCT subjects. For FATT associated shape changes, we found a stronger significant positive correlation in the female CBCT sample group (R^2=0.67, P=0.006) than in the male group (R^2=0.5626, P=0.4434). This stronger relationship of FATT in females indicates that they are rated as being more attractive than the male subjects.

A B

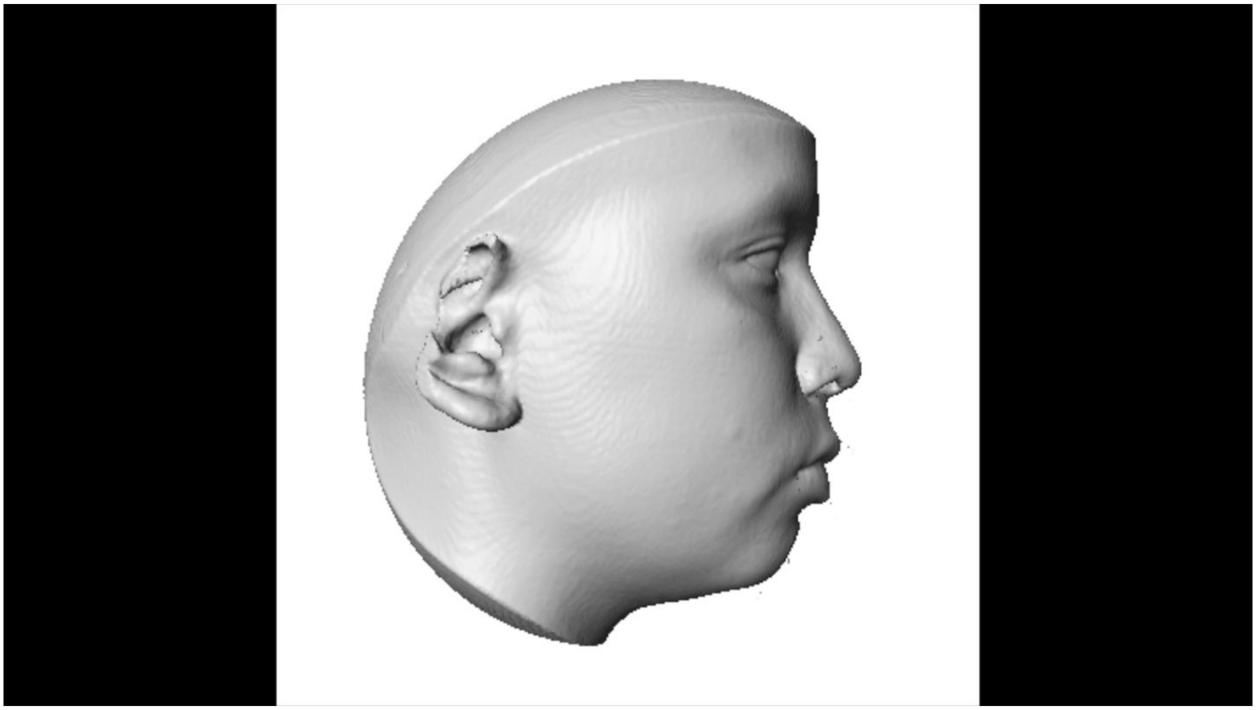
Supplemental Figure 4. A) Skeletal and B) Soft tissue Shape Changes associated with FATT score (all subjects) in MorphoJ software. Profile view. A superior and anterior displacement of the hard tissue chin as compared to an anterior and inferior displacement of the soft tissue chin was observed.



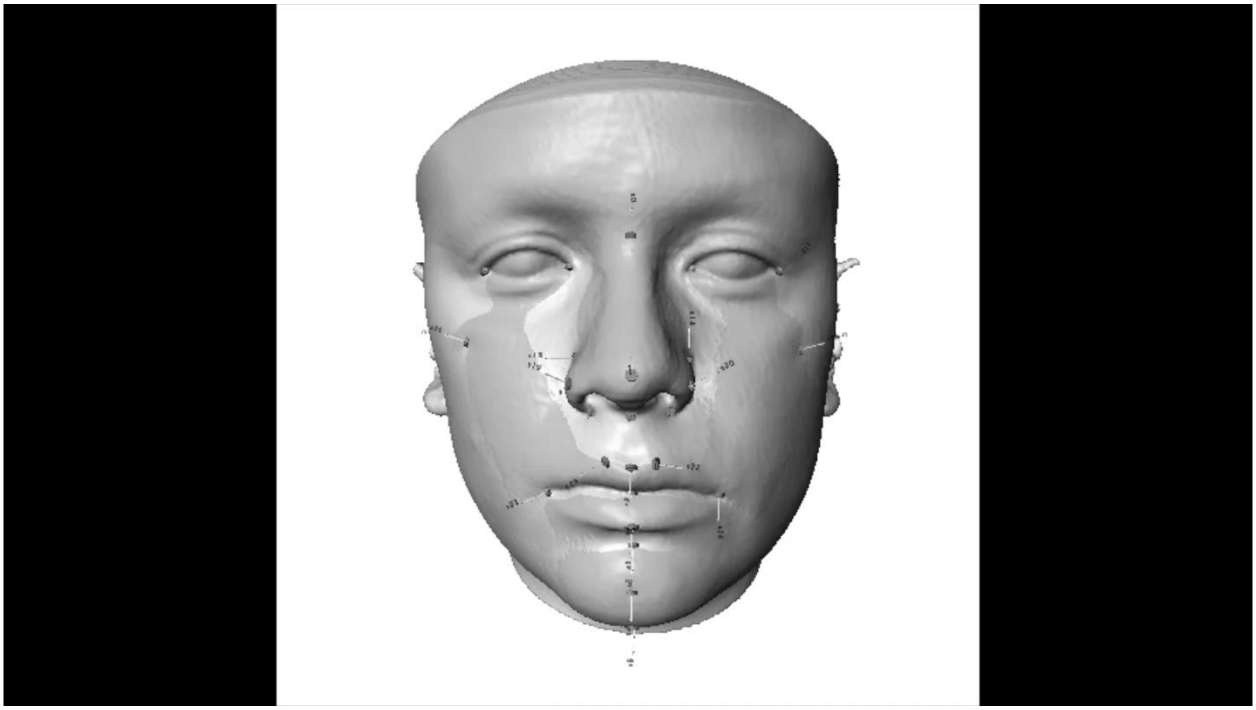
Supplemental Figure 5. M/F in relation to M/F:shape. Each dot indicates each one of the 40 CBCT subjects. The higher the M/F VAS, the more feminine the rating. As a general observation, Female subjects were rated as having more female-like features with an M/F score mainly above 40 (red), while males were rated as having male-like features (blue).



Supplemental Video 2. Video of the average face in the sample morphed to show the extremes for less and more attractive faces as identified by facial attractiveness VAS (FATT). Frontal View.



Supplemental Video 3. Video of the average face in the sample morphed to show the extremes for less and more attractive faces as identified by facial attractiveness VAS (FATT). Profile View.



Supplemental Video 4. Video of the average face in the sample morphed from more masculine to more feminine shape changes.

CHAPTER 4
GENERAL DISCUSSION

4

4.1 Significance of Study

Our findings of distinct skeletal and soft tissue correlates of FATT and SD provide information that can be translated into the clinical aspects of orthodontic/surgical treatment planning and for use in prediction software analyses. Shape transformations using interactive 3D morphed faces allows the visualization of changes that are often seen in two dimensions with silhouettes or photographs. Our approach, therefore, presented a more realistic approach to the evaluation of a face in 3D with results that provides a good framework for further investigations of FATT and SD in the field of orthodontics, oral and maxillofacial surgery and plastic surgery.

The significance and impact of our study lie in the fact that the set of 3D correlates obtained can be used as a “formula” or “recipe” for facial beauty and SD in patients with SSD. Our results represent preliminary findings for the development of an algorithm and groundwork that can be used in artificial intelligence and CASS. Indeed, it would offer a more objective and standardized way of performing orthognathic surgeries by eliminating the subjective esthetic assessment and decision of the surgeon in the planning stage of surgery. Additionally, our findings offer the potential to help predict the amount of surgical movements needed to improve FATT in individual feminine and masculine faces, providing increased understanding in the treatment planning of transgender patients with SSD. Finally, our conclusions provide a useful tool that can be used by health care providers involved in the management of facial deformities, improving the patient’s facial esthetics and therefore their quality of life and well-being.

4.2 Limitations

Due to the subjectivity in defining facial beauty, studies related to FATT or beauty are challenging. In this current study, a few challenges and limitations were encountered.

Differences in ethnicities, educational backgrounds and sex are known confounding factors in studies of FATT and their outcome.[23,203] In the current study, we attempted to lessen the impact of some obvious variables; however, several mitigating factors such as ethnicity, sex and educational background, both in the selection of scans of subjects and the recruitment of the assessors could have compromised our results. For example, our CBCT subjects were from the San Francisco Area and were primarily Blacks and Asians with a very small Caucasian population (Supplemental Table 2). The assessors were recruited primarily from the Greater Toronto Area and largely composed of Caucasian (53%) with a wide variety of different ethnic and racial backgrounds compared to other studies (Table 4).[4,193,215,228,229] Furthermore, there was a higher number of female assessors (65%) as compared to male assessors (35%) in the current study. Thus, the reliability of the ratings for SD in this study might have been impacted by the preponderance of women in the group. As well, judgement of FATT could have been misrepresented by the different age groups and predominantly Caucasian assessors. A possible future study could involve the recruitment of more controlled groups in terms of ethnicities and sex to increase the external validity of this investigation. However, a study of this nature may be restricted by the demographics of the city in which the study may take place. Having the study protocol done in different cities located within the same or different country may permit the selection and recruitment of more targeted and controlled groups of assessors in terms of cultural and ethnic backgrounds.

The CBCT sample selection in the current study comprised 40 scans of different ages. Twelve of our CBCT sample were aged between 15 and 16 years old leading to an average age of 21 years old (range 15 to 35 years old) for this group, while the average age of the assessor's group was 30 years old (range of 19 to 65 years old). Indeed, the disparity in age between our assessors and CBCT sample might have affected the ratings of attractiveness since youthfulness is known to be associated with attractiveness.[222] Similarly, lack of information of the ethnicity of more than half (n=22) of our sample CBCT studies (identified as "other") also prevented the standardization of the CBCT sample. For example, chin and jaw protuberance can be influenced by the ethnic background of the patient.[200,230] However, our current study provides the framework for the design of further studies that can incorporate different skeletal discrepancies (Class I, Class II and Class III), ethnicities and/or age.

Images of the CBCT scans offer an excellent way to eliminate the presence of extrinsic and intrinsic distracting variables (e.g., hair style and/or make-up, skin complexion), therefore focusing the assessor's ratings of FATT specifically on the shape and morphology of the soft tissues of the face (nose, lips and chin). However, it was interesting to note that, in the absence of information of the sex of subjects, the raters were more inclined to evaluate the female subjects as males, consequently altering the evaluation of FATT for those feminine subjects.[182,220] Hence, in contrast to previous studies[23,41,231], we found that an increase in masculine features (chin and nose prominence as well as thinner lips) were associated with better rating of attractiveness for female faces. We could have resolved this issue by letting the assessors know if they were looking at a male or a female face for their rating of FATT. However, this would have altered the evaluation of masculinity and femininity for each rater in our specific study. A solution to this limitation would have been to run two different sessions per rater, one for FATT where sex of the face is given, and one for rating of masculinity and femininity. Nevertheless, this would have been more time consuming for both the raters and the invigilator.

The chin was determined to be one of the major drivers for FATT in our study. However, only two soft-tissue landmarks (gnathion and pogonion) were used to measure the shape of the chin and previous studies have shown that there is great variability of shape measurement at pogonion.[232,233] Hence, future investigations in FATT studies should incorporate more landmarks to provide more precise morphological shape information (e.g., mediolateral shape changes).[220] This task could be extended not only to the pogonion but also at the lips, cheeks and nose, to allow greater precision in capturing shape measurements and changes. In increasing the number of landmarks, however, one has to bear in mind the increase in labor-intensity of the entire project.

For convenience, FATT assessment was executed in a room with multiple assessors at one time. Although the participants were asked not to talk among each other, sound of exclamation or surprise were sometimes heard which could have influenced the other raters. A better way to control for this would be to have each individual alone in the room. However, that would restrict our ability to recruit a larger sample.

Our sample CBCT group was not assessed to be very attractive in this study as the maximum rating value of FATT was 74 out of 100. This could be explained by the fact that CBCT images are only “proxies” of real faces whereby skin color and texture, hair style and eye color were missing.[19,22] The use of actual images of faces in 3D, e.g., three-dimensional photogrammetry that can capture surface geometry without removing extrinsic facial features[19,64] would be beneficial to undertake as these images may offer a closer representation of faces for evaluation of facial beauty.

Lastly, since FATT is defined by the soft tissue of the face, which is itself defined by the underlying skeleton, it would have been of interest to study the relation of the soft tissue and skeletal changes in attractive SSD faces. The current study was mainly limited to soft tissue assessment of FATT; a very limited analysis of this soft-tissue-to-skeletal relation was achieved by roughly looking at the vector displacement direction and magnitude. In future study, it would be interesting to look at the direct relationships of the soft and hard tissues to help determine whether a set of predictable and consistent skeletal movements to achieve a certain soft tissue goal exists.

CHAPTER 5
CONCLUSION

5

5.1 Conclusion

The results of this study confirmed the hypothesis that individuals with SSD possess defined 3D facial characteristics of FATT and SD. A chin that is positioned anteriorly, a reduced upper lip projection and a shorter lower lip height had the strongest impact on FATT compared to other facial features. Our findings support the idea that balanced maxillary-mandibular skeletal relationship (ANB value of 0° to 3.6°) is the most consistent predictor of perceived attractiveness. Prominent cheeks and posterior displacement of the tip of the nose and chin were significantly associated with a more feminine facial appearance. Our findings provide guidance in the orthodontic/surgical treatment planning of patients with SSD with potential to help predict the amount of surgical advancement needed to improve FATT in individual faces, taking sex/gender into consideration.

5.2 Future Directions

The novelty of this study lies in the use of CBCT 3D volumes and sophisticated Procrustes-based geometric morphometrics analyses to perform shape transformations and interactive 3D face morphing to visualize facial changes that differentiate an attractive versus a non-attractive face.[234,235] An immediate next step for our research would be to test our morphed "unattractive" and "attractive" faces in a new sample. This would confirm that these shape changes are indeed what is considered attractive in the SSD population. As well, the Procrustes-based GM method could be widely used in future studies to look at how other variables of attractiveness (youthfulness and symmetry) could affect shape changes of individuals as rated by laypeople.[60,64]

In our study, obtaining the raters' anxiety profile helped control for the observer's subjectivity in FATT ratings and provided preliminary information for future studies in this field. Since judgement of attractiveness could be affected by the assessor's feelings and mood[53,55,236], future studies should incorporate a more thorough psychological assessment of their evaluators in their methods and protocol.

Furthermore, a similar study should be conducted with Skeletal Class III patients which would help differentiate between our two major patient population groups that present for jaw surgery (Skeletal Class II and Skeletal Class III malocclusions). Finally, the use of electronic VAS and web-based crowdsourcing could be applied to recruit more participants across different geographic locations.

CHAPTER 6
APPENDICES

Appendix A Ethics Approval

A1. University of Toronto, Review Ethics Board Approval and Renewals

UNIVERSITY OF TORONTO

OFFICE OF THE VICE-PRESIDENT, RESEARCH AND INNOVATION

RIS Protocol Number: 36419

Approval Date: 14-Sep-18

PI Name: Janick Decoste

Division Name:

Dear Janick Decoste:

Re: Your research protocol application entitled, "Three Dimensional Morphological Correlates of Facial Attractiveness in Patients with Class II Skeletal Malocclusion"

The "Health Sciences" REB has conducted a "Delegated" review of your application and has granted approval to the attached protocol for the period 2018-09-14 to 2019-09-13.

Please be reminded of the following points:

- An **Amendment** must be submitted to the REB for any proposed changes to the approved protocol. The amended protocol must be reviewed and approved by the REB prior to implementation of the changes.
- An annual **Renewal** must be submitted for ongoing research. You may submit up to 6 renewals for a maximum total span of 7 years. Renewals should be submitted between 15 and 30 days prior to the current expiry date.
- A **Protocol Deviation Report** (PDR) should be submitted when there is any departure from the REB-approved ethics review application form that has occurred without prior approval from the REB (e.g., changes to the study procedures, consent process, data protection measures). The submission of this form does not necessarily indicate wrong-doing; however follow-up procedures may be required.
- An **Adverse Events Report (AER)** must be submitted when adverse or unanticipated events occur to participants in the course of the research process.
- A **Protocol Completion Report** (PCR) is required when research using the protocol has been completed. For ongoing research, a PCR on the protocol will be required after 7 years, (Original and 6 Renewals). A continuation of work beyond 7 years will require the creation of a new protocol.
- If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your research.

OFFICE OF RESEARCH ETHICS
McMurrich Building, 12 Queen's Park Crescent West, 2nd Floor, Toronto, ON M5S 1S8 Canada
Tel: +1 416 946-3273 ● Fax: +1 416 946-5763 ● ethics.review@utoronto.ca ● http://www.research.utoronto.ca/for-researchers-administrators/ethics

UNIVERSITY OF TORONTO

OFFICE OF THE VICE-PRESIDENT, RESEARCH AND INNOVATION

RIS Protocol Number: 36419

Approval Date: 3-Sep-19

PI Name: Janick Decoste

Division Name:

Dear Janick Decoste:

Re: Your research protocol application entitled, "Three Dimensional Morphological Correlates of Facial Attractiveness in Patients with Class II Skeletal Malocclusion"

The Health Sciences REB has conducted a Administrative review of your application and has granted approval to the attached protocol for the period 2019-09-03 to 2020-09-13.

Please note that this approval only applies to the use of human participants. Other approvals may be needed.

Please be reminded of the following points:

- An **Amendment** must be submitted to the REB for any proposed changes to the approved protocol. The amended protocol must be reviewed and approved by the REB prior to implementation of the changes.
- An annual **Renewal** must be submitted for ongoing research. You may submit up to 6 renewals for a maximum total span of 7 years. Renewals should be submitted between 15 and 30 days prior to the current expiry date.
- A **Protocol Deviation Report** (PDR) should be submitted when there is any departure from the REB-approved ethics review application form that has occurred without prior approval from the REB (e.g., changes to the study procedures, consent process, data protection measures). The submission of this form does not necessarily indicate wrong-doing; however follow-up procedures may be required.
- An **Adverse Events Report (AER)** must be submitted when adverse or unanticipated events occur to participants in the course of the research process.
- A **Protocol Completion Report** (PCR) is required when research using the protocol has been completed. For ongoing research, a PCR on the protocol will be required after 7 years, (Original and 6 Renewals). A continuation of work beyond 7 years will require the creation of a new protocol.
- If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your research.

OFFICE OF RESEARCH ETHICS
McMurrich Building, 12 Queen's Park Crescent West, 2nd Floor, Toronto, ON M5S 1S8 Canada
Tel: +1 416 946-3273 ● Fax: +1 416 946-5763 ● ethics.review@utoronto.ca ● http://www.research.utoronto.ca/for-researchers-administrators/ethics

A2. University of California San Francisco, Review Ethics Board Approval

UCSF
University of California
San Francisco

Human Research Protection Program
Institutional Review Board (IRB)

Expedited Review Approval

Principal Investigator
Nathan Young, PhD

Co-Principal Investigator
Ralph Marcucio, PhD

Type of Submission:	Continuing Review Submission Form
Study Title:	Facespace: predictive three-dimensional orofacial shape and growth

IRB #:	11-06996
Reference #:	217583
Committee of Record:	Laurel Heights Panel
Study Risk Assignment:	Minimal

Approval Date: 04/04/2018 **Expiration Date:** 04/03/2019

Regulatory Determinations Pertaining to this Approval:
This research satisfies the following condition(s) for the involvement of children:
45 CFR 46.404, 21 CFR 50.51: Research not involving greater than minimal risk.

The requirement for individual Research HIPAA Authorization is waived for all subjects. The use or disclosure of the requested information does not adversely affect the rights and welfare of the individuals and involves no more than a minimal risk to their privacy based on, at least, the presence of the following elements: (1) an adequate plan to protect the identifiers from improper use and disclosure; (2) an adequate plan to destroy the identifiers at the earliest opportunity consistent with conduct of the research, unless there is a health or research justification for retaining the identifiers or if such retention is otherwise required by law; (3) adequate written assurances that the requested information will not be reused or disclosed to any other person or entity, except as required by law, for authorized oversight of the research study, or for other research for which the use or disclosure of the requested information would be permitted by the Privacy Rule; (4) the research could not practicably be conducted without the waiver; and (5) the research could not practicably be conducted without access to and use of the requested information.

A waiver or alteration of informed consent is acceptable because, as detailed in the application: (1) the research involves no more than minimal risk to the subjects; (2) the waiver or alteration will not adversely affect the rights and welfare of the subjects; (3) the research could not practicably be carried out without the waiver or alteration; and (4) whenever appropriate, the subjects will be provided with additional pertinent information after participation.
The waiver or alteration of informed consent applies to all subjects.

This submission was eligible for expedited review as:
Category 5: Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis)

Appendix B Informed Consent

PATIENT INFORMATION AND CONSENT

UNIVERSITY OF TORONTO
FACULTY OF DENTISTRY

Three-Dimensional Shape of Facial Attractiveness in Patients with Sagittal Skeletal Dysplasia

Patient Information & Consent Form

Purpose of the Study

The purpose of this study is to identify characteristics of the face using three-dimensional (3D) black and white images of patients to determine what makes a face attractive or less attractive. The study will be conducted by Dr. Janick Decoste, who is a dentist and a graduate orthodontic resident at the Department of Orthodontics, Faculty of Dentistry, University of Toronto, under the supervision of Dr. Siew-Ging Gong, who is a Professor at the Faculty of Dentistry.

Procedures

This research will be involving only those who choose to take part. This information and consent form describes the study so you can make an informed decision on participating. Please feel free to ask questions if anything is unclear or there are words or phrases you do not understand.

The Burden of the Study for Participants

This study will take around 30 min.
If you agree to participate, you will be asked to:

- Present to our designated room at 124 Edward street
- Fill 2 questionnaires
- View 3D images of faces on a projector screen and rate their attractiveness

Rating of Facial Attractiveness

You will be asked to rate the attractiveness of faces that you will be viewing on a projector screen. For each image, you will be asked to rate the faces using a Visual Analog Scale (VAS) which is a horizontal line anchored by the words “very unattractive” and “very attractive”. As well, you will be asked to rate whether the face is a Male or a Female face. You will be asked to place a vertical line on this horizontal scale that will represent the rating of this face to you as well as it’s femininity or masculinity.

Would you like to take part in this study?

We would like to kindly invite you to take part in this study. Participation is voluntary and you may refuse to participate or withdraw at any moment without any repercussions. You do not need to provide a reason for withdrawing. All the data collected before your withdrawal will be kept securely and indefinitely.

Benefits

There is no direct benefit for the participant, but the orthodontic community will benefit from this study in understanding what makes a face more beautiful than another. Thus, it will guide us in helping patients who are unhappy with their facial esthetics. The information may be useful for clinicians to better tailor their orthodontic treatment strategies and to improve the dentofacial esthetics of the patients and improve their psychological well-being.

Privacy Statement

We are committed to protecting your personal information and respecting your privacy. Personal information is defined as any details that will enable you to be identified, such as ID numbers, telephone numbers, address, email address etc. When designing, and executing our research, it is our policy to take all necessary steps to ensure that any personal information you provide is processed fairly and lawfully. Only authorized staff has access to personal information and they are obliged to respect its confidentiality. We do not sell, rent or exchange any personal information supplied by you to any third party. Nor do we use any of the information you provide for direct marketing or other non-research activities.

All the information you will provide will be property of the Faculty of Dentistry, University of Toronto. Only the investigators listed in this document will have access to the data. Your research data will be stored at the Faculty of Dentistry. The data will be kept indefinitely and used for further research studies, if you give your consent. You may be contacted for follow-up or for inviting you to participate in other investigations.

The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team

In obtaining your cooperation to participate in the survey, we undertake not to mislead you in any way about the nature of the research we are conducting, the way in which the data are collected and the use that will be made of the survey results. All the information that you provide will be treated as confidential and together with your research data will only be used for this or any other research purposes. Your comments will not be identified as belonging to you; instead, they will be combined with those gathered from other survey participants and will be analyzed as part of a group.

We do not use any of the information you provide for direct marketing or other non-research activities. If we ask you for personal information that enables you to be identified - e.g., your name, ID numbers, email address or telephone number, we will clearly state why we are asking for it and for your permission to use it for that purpose. For example, it might be to contact you for other research studies. Your participation is voluntary. You are entitled to ask that part, or all, of the record of your involvement in the survey be deleted or destroyed.

The results of this research study will be object of publication or research presentations. You can request a summary of the research results to the investigators, who will be pleased to send it to you by email. As the data from this research project will require time to analyze, it is not possible to fully explain the results of this study while it is still in progress; however, participants will be provided will be informed about the results of the research at the end of this study.

This research is economically supported by the research funds of the Research Supervisor and by the Faculty of Dentistry, University of Toronto.

You can contact the Office of Research Ethics at ethics.review@utoronto.ca or 416-946-3273 if you have questions about your rights as participant

Dr. Janick Decoste (Investigator)	**Dr. Siew-Ging Gong (Supervisor)**
Janick.decoste@mail.utoronto.ca University of Toronto Faculty of Dentistry Graduate Orthodontic Dept 124 Edward Street Toronto, Ontario	sg.Gong@dentistry.utoronto.ca University of Toronto Faculty of Dentistry Orthodontics Dept. Rm 509 124 Edward Street Toronto, Ontario

I voluntarily consent to participate in this study and will be given a signed copy of this form to take home with me.

Name: _________________________ Surname: ___________________________

Phone Number: _________________Email Address: ______________________

☐ I agree ☐ I disagree Signature: __________________________

I voluntarily consent to be contacted for future studies YES NO

Name: _________________________ Surname: ___________________________

Phone Number: _________________Email Address: ______________________

☐ I agree ☐ I disagree Signature: __________________________

Appendix C Questionnaires

C1. Demographic Questionnaire

QUESTIONNAIRE #1

Demographics

DIRECTIONS: Please answer each question as accurately as possible by circling the correct answer or filling in the space provided.

1. What is your gender:

☐ Male ☐ Female ☐ Other: ________

2. What is your age: ____

3. What is your ethnicity?

☐ Canadian

☐ French

☐ English

☐ German

☐ Scottish

☐ Irish

☐ Italian

☐ Ukrainian

☐ Dutch (Netherlands)

☐ Chinese

☐ Jewish

☐ Polish

☐ Portuguese

☐ South Asian (e.g., East Indian, Pakistani, Sri Lankan, etc.)

☐ Norwegian

☐ Welsh

☐ Swedish

☐ First Nations (North American Indian)

☐ Métis

☐ Inuit

☐ Other - Specify

3. What is your race? Mark all that apply

☐ Aboriginal/First Nations

☐ White

☐ South Asian (e.g., East Indian, Pakistani, Sri Lankan, etc.)

☐ Chinese

☐ Black

☐ Filipino

☐ Latin American

☐ Arab

☐ Southeast Asian (e.g., Vietnamese, Cambodian, Malaysian, Laotian, etc.)

☐ West Asian (e.g., Iranian, Afghan, etc.)

5. What is the highest grade or level of schooling that you have completed?

☐ Less than high school diploma or its equivalent
☐ High school diploma or a high school equivalency certificate
☐ College, CEGEP or other non-university certificate or diploma
☐ University certificate or diploma below the bachelor's level
☐ Bachelor's degree (e.g., B.A., B.Sc.)
☐ University certificate, diploma, degree above the bachelor's level

6. Are you currently a student? _______________

If yes, grad or undergrad? _______________

In what discipline? ________________

Thank you for taking the time to complete this questionnaire.

C2. State-Trait Anxiety Inventory

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

DIRECTIONS

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I am "calm, cool, and collected"	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn't matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me	1	2	3	4
38. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

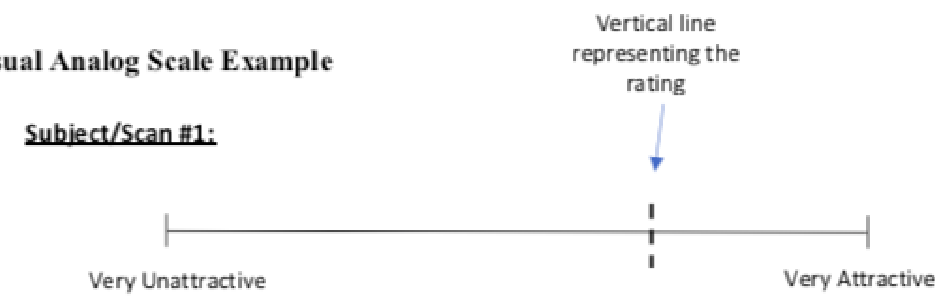
Appendix D Visual Analog Scales (VAS) and Rating of Facial Attractiveness

D1. Explanation and Instruction Page for VAS

RATING OF FACIAL ATTRACTIVENESS

You will be asked to rate the attractiveness of faces that you will be viewing on a 3D digital software. For each image, you will be asked to rate the faces using a Visual Analog Scale (VAS) which is a horizontal line anchored by the words "very unattractive" and "very attractive". **For each face viewed, we ask you to place a vertical line or an "x" on this horizontal scale that will represents the rating of this face to you. You will be asked to do the same with the visual analog scale "Male" and "Female".** We would ask you to please remain in silence during this evaluation.

Figure 1. Visual Analog Scale Example



Please Evaluate Facial Attractiveness and Sex of the ''Example Face'':

Very Unattractive Very Attractive

Male Female

Please turn the page to start evaluating the faces. There will be 48 images to evaluate in total.

D2. Actual Evaluation Page (example of page 1 out of 13)

POWERPOINT # : ______

Please Evaluate Facial Attractiveness and Sex of Subject #1

Very Unattractive | Very Attractive

Male | Female

Please Evaluate Facial Attractiveness and Sex of Subject #2

Very Unattractive | Very Attractive

Male | Female

Please Evaluate Facial Attractiveness and Sex of Subject #3

Very Unattractive | Very Attractive

Male | Female

Please Evaluate Facial Attractiveness and Sex of Subject #4

Very Unattractive | Very Attractive

Male | Female

Please Evaluate Facial Attractiveness and Sex of Subject #5

Very Unattractive | Very Attractive

Male | Female

Appendix E Room in which the viewing and rating procedure were conducted

Figure 31. Room 360, 3rd Floor, at 124 Edwards Street, Faculty of Dentistry.

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