COMPARING 3D & 2D FACIAL PHOTOGRAPHY TO CLINICAL FACIAL FORM ANALYSIS FOR ORTHODONTIC DIAGNOSIS

by

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University of Pittsburgh, 2015

The primary goal of orthodontic treatment is a functional dental occlusion as well as an aesthetic smile in harmony with the lower 1/3 facial soft tissue. A 3-dimensional analysis of the patient's dentofacial relations is crucial for proper treatment planning and it is ultimately the soft tissue that dictates the direction of the orthodontic treatment plan (Sarver 2001). The purpose of this pilot study is to study the difference of three different medias (3D photography, 2D photography, clinical patient evaluation) for facial form analysis. Specifically, to determine which photographic method most closely mimics clinical analysis of facial form for the purpose of orthodontic facial form diagnosis. Two orthodontists analyzed twelve facial measurements on 54 patients (21 male) via 3D photographs, 2D photographs and clinical evaluations. In addition, twelve of these patients were randomly chosen for two extra evaluation sessions for intra-rater reliability testing. The twelve categories are the most commonly used measurements by orthodontists to evaluate lower 1/3 facial form for diagnosis and treatment planning purposes. Krippendorff's Alpha reliability testing was used with values >0.6 deemed substantially reliable. Results showed poor intra-rater reliability for both evaluators across all three media (only 22 out of 72 total categories substantially reliable) demonstrating the examiners were not reliably consistent with their evaluations. Furthermore, results showed poor reliability testing between the three different medias making comparisons of 3D vs. 2D vs. clinical evaluation difficult. Lastly, results showed poor inter-rater reliability for the two evaluators across all three media (zero substantially reliable categories) demonstrating that the two examiners did not agree on any of the facial evaluations. In conclusion, the two orthodontist did not reliably diagnose most of the 12 facial categories using the three given media of clinical, 2D photography and 3D photography and they also did not agree with each other's diagnosis; therefore, it is difficult to determine if 2D or 3D photography provides more diagnosis similarities to clinical evaluation of facial form diagnosis.

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PREFACE

Dedicated to my loving parents, Dr. Esmail Zamani, M.D. and Pari Dalili. Without their sacrifice and constant love and support, none of this would have ever been possible. Merci!

1.0 INTRODUCTION

1.1 FACIAL ATTRACTIVENESS

It has been shown that attractive men and women are perceived as being more intelligent and personable, having better job success and, in general, more socially fulfilled when compared to their less attractive counterparts (Dion 1972, Langlois 2000). Studies have shown that attractiveness plays a role at the voting polls in political races and in the classroom with teacher and student interactions (Clifford 1973, Efran 1974). Attractiveness impacts more than how one is perceived by others it has also been shown to influence the individual's personality development, which can dictate their social, emotional and intellectual traits (Van der Geld 2007). The importance of human attractiveness to social interaction has proven to be at least partially innate. For example, the medial orbito cortex, the cranial region associated with stimulus and reward, is activated by attractive faces. Interestingly, a smile also activates this cranial region, signifying a physiological connection between attractiveness, smiling and our perception of others (O'Doherty 2003). We respond to beautiful faces as early as several weeks after birth, as infants have been shown to prefer attractive faces versus unattractive faces (O'Doherty 2003).

The human face has been shown to be the most important aspect of physical attractiveness (Riggio 1991). People normally judge initial personality based on facial appearance (Jornung and Fardal 2007). On the face, the eyes and teeth have been shown to be the most important aspect of attractiveness as well as the centers of attention during social interaction (Thompson 2004, Jornug 2007). The smile and dental aesthetics have been shown to be important contributors to facial attractiveness. Individuals who smile more often have even been shown to be perceived as more trustworthy (Krishnan 2008). For these reasons, it is important for orthodontists to consider the hard and soft tissue aspects of a smile when treating patients.

1.2 ORTHODONTICS AND FACIAL FORM CHANGES

The primary goal of orthodontic treatment is a functional dental occlusion as well as an aesthetic smile in harmony with the lower 1/3 facial soft tissue. For complete patient satisfaction, the aesthetic balance between tooth alignment, gingival contour, and their relation to the nose, lips and chin must be achieved (Janzen 1977). Most patients can be treated with orthodontics alone. For patients who have severe dental and/or skeletal discrepancies, the orthodontist and surgeon must plan an interdisciplinary treatment that addresses both functional dental occlusion as well as hard and soft tissue aesthetics. These patients often have severe facial soft tissue form disharmony that could be perceived as aesthetically unpleasing. For example, patients with skeletal discrepancies, vertical excess, protrusion, retrusion and/or cant of the maxilla and/or mandible, require orthognathic surgery for proper dental and facial soft tissue alignment and harmony. Clinically significant changes due to orthodontic and/or orthognathic treatment can specifically be seen in the upper and lower lips, angulation of the tip of the nose and alar base, strain of the mentalis muscle and/or the position and size of the chin. For these orthodontic/orthognathic patients, evaluation of the soft tissue is even more crucial in the preliminary diagnoses and treatment planning phase.

The clinician must also take into account the complexity of the growing face and the physical changes that occur with the aging process. The majority of facial changes occur up to the age of 18 years with minor growth and facial form change occurring throughout life. With age, the nose and chin enlarge and the lips thin and become more retrusive resulting in a more concave profile (Nanda 1990). Orthodontic treatment has the ability to expand the dental arches, which may extend the soft tissue envelope and provide better support for the upper and lower lips as well as the perioral tissue. This increased soft tissue fullness counteracts the effects of aging, including decreased perioral and lip support, and results in a younger appearance for the patient (Sarver 2001). This paradigm can direct the orthodontic diagnosis and determine a treatment option of tooth extraction and arch constriction or a non-extraction treatment with dental arch expansion.

The effects of orthodontic treatment, particularly dental extraction and incisor position change, has been significantly studied and published in dental literature and there seems to be a range of theories. Spahl stated, "extraction of teeth makes the dental arches smaller, 'sinked in' lip support and makes the smile smaller, constricted and makes the extraction patient seem older" (Spahl 1986). Other studies determined that orthodontic treatment can alter the profile and lip support, but the variation in this soft tissue support is vast and it is difficult to reliably predict soft tissue change with orthodontic treatment (Rudee 1964, Hershey 1972, Roos 1977, Collett 2006). A careful diagnosis of incisor and lip procumbency can indicate dental extraction, which will result in better facial harmony and attractiveness (Bowman 2000). In fact, one study determined that in certain cases facial attractiveness will be compromised without the inclusion of dental extraction in the orthodontic treatment (Kocadereli 2002).

1.3 FACIAL FORM DIAGNOSIS

For the reasons stated above, a 3-dimensional analysis of the patient's dentofacial relations is crucial for proper treatment planning and it is ultimately the soft tissue that dictates the direction of the orthodontic treatment plan (Sarver 2001). Currently, an orthodontic diagnosis and treatment plan is based on clinical, radiographic and photographic analysis and measurements. High quality photographs are necessary to document the pre-treatment status as well as the post treatment results of the patient, to aid in patient education and communication, for medico-legal purposes, for pre-surgical planning, and also for the teaching of orthodontic residents (Honrado 2004).

Orthodontists normally evaluate soft tissue form via a clinical exam with 2D photographs and a cephalometric radiograph, with extraoral 2D profile photographs normally the primary soft tissue evaluation tool. In the private clinic setting, clinicians use the facial photographs to either confirm what they remember from their clinical patient soft tissue analysis or simply use the photographs as their primary tool for facial analysis. In orthodontic residency programs, 2D photography is the primary tool for facial form analysis due to the academic setting where pictures are used as a teaching tool. It has been suggested this technique is inadequate as 2D profile photographs are an, "imperfect reflection of what exists clinically" and they fail to show how the public sees the patient and how the patient see themselves. Treatment planning a 3D patient in 2D is insufficient as, "facial depth and shape are not accounted for" (Da Silveira 2003). 2D facial photographs are prone to distortions in magnification, the patient's head posture/position as well as the camera position and the 2D frontal photographs often fail to reveal skeletal asymmetries (Sarver 2001).

The experienced clinician also currently uses the cephalometric soft and hard tissue measurements as a confirmation for the clinically based facial form diagnoses. We cannot rely on hard tissue dentoskeletal cephalometric measurements to predict facial soft tissue aesthetics (Park, Burstone, 1986). "Orthodontic treatment, by altering the dentoskeletal framework, may produce desirable or undesirable alterations in the external or integmental contours of the face" (Burstone 1958). Burstone demonstrated over fifty years ago that cephelometric measurements of the dental and skeletal structures cannot predictably determine the soft tissue drape because, "soft tissue may vary in different persons in thickness, length, and postural tone" and it is necessary to directly evaluate the soft tissue. Cephalometric soft tissue readings are inadequate as they solely show the midsaggital soft tissue while ignoring most of the other facial soft tissue (Honrado 2004). Raiedel attempted to quantify beauty using angular and linear cephalometric measurements by analyzing 30 beauty queens. The study showed significant individual variation, for example the lip thickness of the subject ranged from 8.5 to 16mm, showing cephalometric numbers could not define beauty (Ridel 1957).

In 2001, Sarver explained, "Because orthodontics does not yet have morphometric tools for soft tissue evaluation that are comparable in quality and accuracy to those measuring dental and skeletal components, orthodontists must place greater emphasis on the physical examination of the patient. This examination requires using skills they have not performed to a great degree previously and therefore are not accustomed to using." (Sarver 2001) Because 2D and cephalometric soft tissue analysis have been shown to be an imperfect means for facial form diagnosing, we must currently rely on clinical patient soft tissue evaluation. The following list is an amalgamation of the “gold standard” of facial form analysis. However, most orthodontists do not analyze every facial form measurement described below because there is currently a myriad of facial form analysis that orthodontists use without a major consensus on which is the most appropriate and practical. Finally, it is important to remember, “facial evaluation is not the search for a deviation from the norm of a single subunit, but the appraisal of proportions.” (Reynak 2012).

1.4 AMALGAMATION OF THE “GOLD STANDARD” OF FACIAL FORM ANALYSIS

The following list demonstrates frontal and profile view facial measurements that could be used for orthodontic hard and soft tissue diagnosis. This list does not include every facial form analysis, but rather the major measurements analyzed by orthodontists. The italicized captions following the images are directly copied from the Reyneke, 2012 article.

1.4.1 Frontal View (Figures 1-5):

1) Facial Form (Reyneke 2012)

The proportion of facial width to length is most important when evaluating the facial form. The height width proportion (trichion to menton: bizygomatic width) is 1.3:1 for females and 1.35:1 for males with the bigonial width being 30% less than the bizygomatic width (Farkas LG 1987).

2) Vertical proportions of the frontal view of the face at rest (Sarver 2001)

a. The most accepted aesthetic proportions are equal heights of facial thirds. Within the lower facial third, the upper lip should comprise 1/3 and the lower lip + chin should comprise 2/3 of the vertical height.
b. You must evaluate the philthrum height and its relation to the commissure. Ideally, the philthrum should be 2-3mm shorter than the commissure height.
c. You must evaluate lip vermilion show, lip incompetence, mentalis strain, and mandibular asymmetries.
d. Normal upper lip length is 20 +/- 2mm for females and 22 +/- 2mm for males when measured from subnasale to stomion superiorus. Normal lower lip length is 40+/- 2mm for females and 44 +/- 2mm for males when measured from stomion inferiorus and B point. Certain conditions like a deep bite or vertical maxillary excess or deficiency can alter these numbers (Reyneke 2012).

3) Transverse Dimensions (Reyneke 2012)

The face is divided into five equal parts starting from the helix of the outer ear.

4) Facial asymmetry (Reyneke 2012)

Evaluate facial asymmetries in the nose, maxilla, mandible, the chin, or any combination of the above. A dental evaluation for a cant must be conducted as this can also result in skeletal asymmetries.

5) Lips (Reyneke 2012)

a. Evaluate for lip asymmetry that could be caused due to myriad of causes including dentoskeletal deformities.
b. Evaluate interlabial gap in repose, with 1-4mm considered optimal.
c. Evaluate vermilion area, with the lower lip generally showing 25% more vermillion than the upper lip. Protrusion or retrusion of the upper and lower incisors will alter the vermillion show.

6) Nose

The nasal shape can be altered with orthognathic surgery and the nose is also considered a component of treatment for many orthognathic surgeons. For this reason, the orthodontist should evaluate the nose size, shape and symmetry (including alar base, nostrils, and dorsum.) (Reyneke 2012)

7) Cheeks

There should be a smooth soft tissue line starting from the front of the ear and extending over the cheekbone and down over the maxilla adjacent to the ala of the nose and finally ending next to the lip commissures. Any discontinuity of this line may indicate maxillary or mandibular skeletal deformity. (Reyneke 2012)

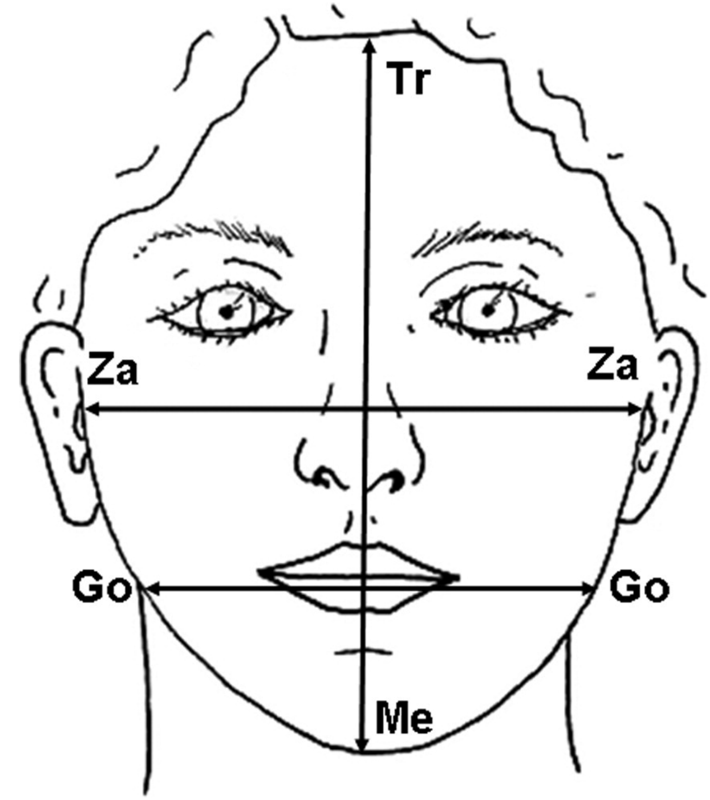

Figure 1 ***Height to Width relationship of the face. The relationship of the height of the face (Tr-Me) to the width (Za-Za) should be 1.3:1 for females and 1.35 for males. The bigonial (Go-Go) width should be approximately 30% less than the bizygomatic (Za-Za) width. (Reynake 2012)***

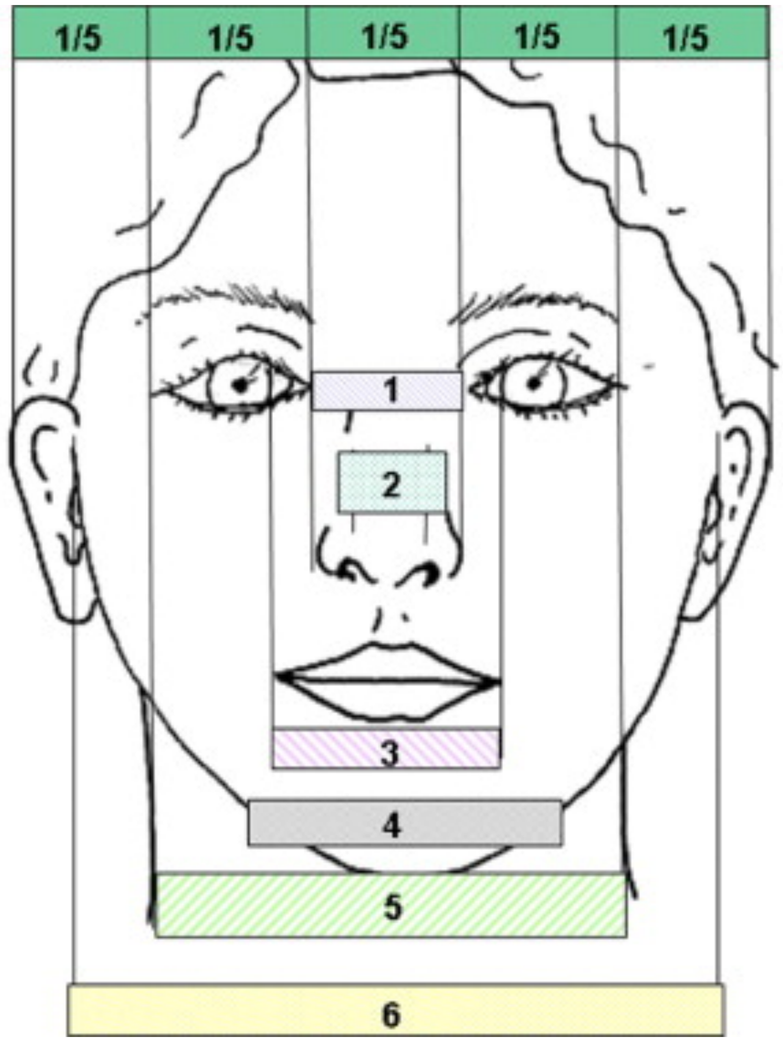

Figure 2 ***Transverse facial proportions and facial form. The "rule of fifths" is a convenient method of evaluating transverse proportions. The intercanthal width should be equal to the alar base width (1), the width of the nasal dorsum should be approximately half the alar base width (2), the width of the medial irides of the eyes should coincide with the corners of the mouth (3), the width and shape of the chin should be in harmony with the rest of the face (4), the Gonion should fall on a line drawn through the outer canthus of the eye (5), and the bigonial width is usually 30% less than the bizygomatic width (6). (Reyneke 2012)***

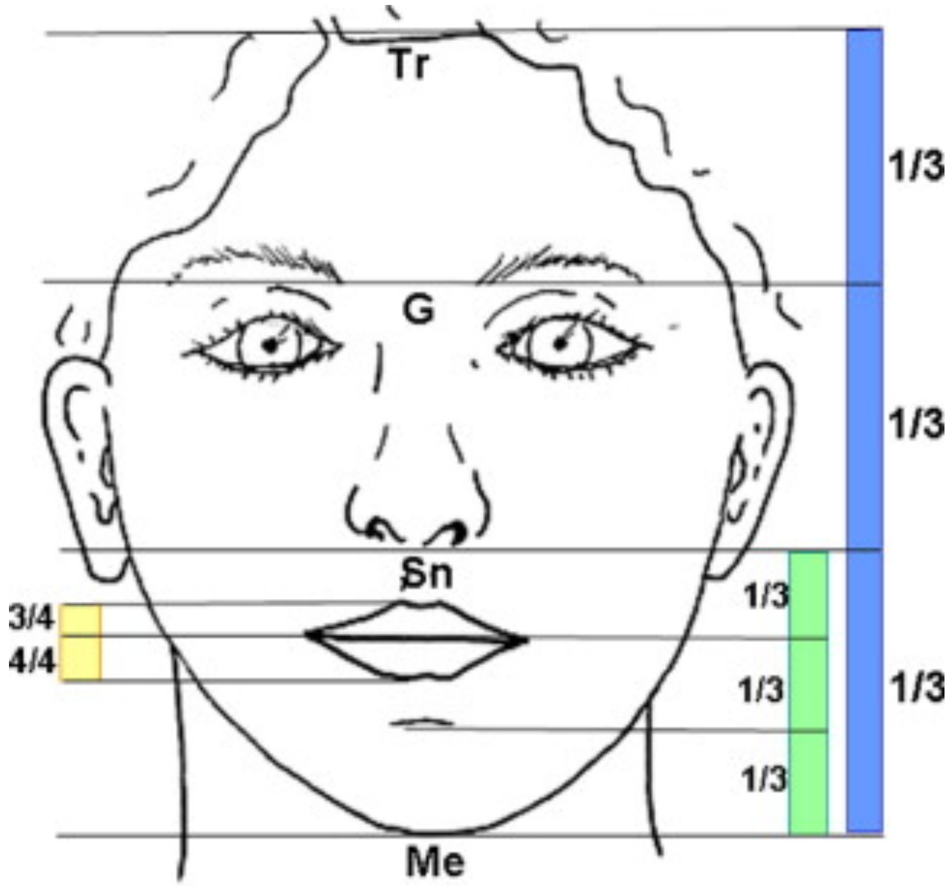

Figure 3 *Vertical relations. The face can be divided into 3 parts from trichion to menton. The upper third from trichion (Tr) to glabella (G), the middle third from glabella (G) to subnasale (Sn), and the lower third from subnasale (Sn) to menton (Me). The lower third can further be divided into an upper third, the upper lip, which from subnasale (Sn) extends to upper-lip vermillion, and a lower two-thirds, which extends from the lower-lip vermillion to menton (Me). The labiomental fold will divide the lower-lip/chin area into equal parts. The vermillion of the lower lip is usually about 25% larger than the upper-lip vermillion. (Reyneke 2012)*

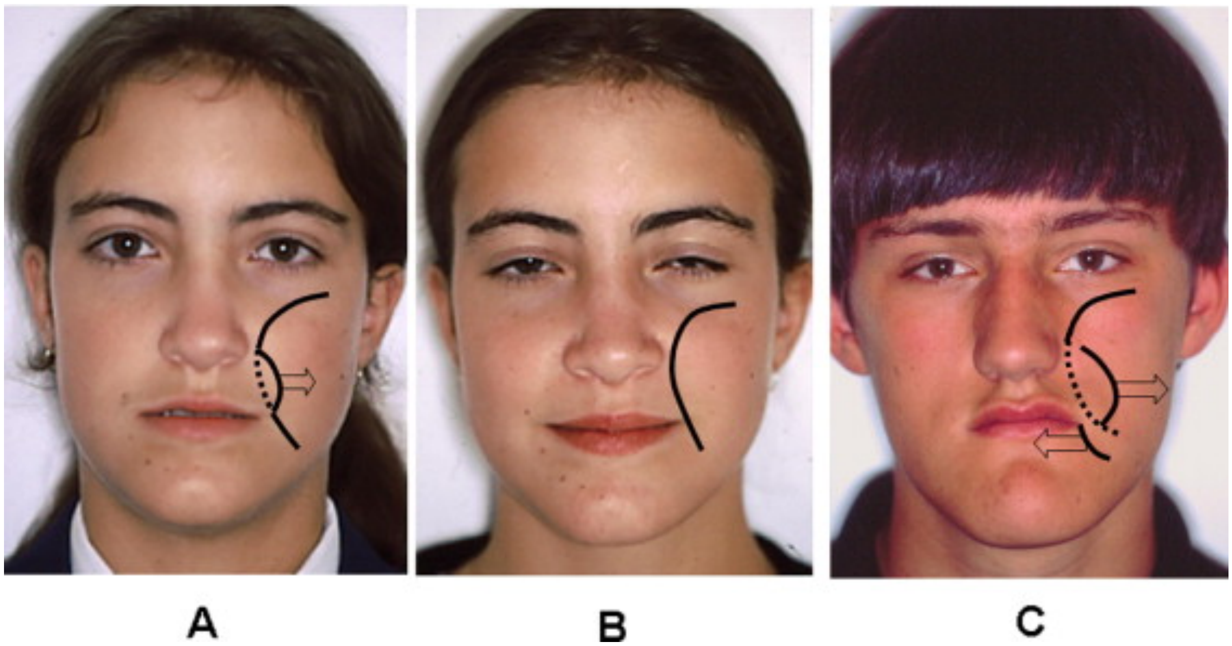

Figure 4: ***The cheekbone–nasal base–upper lip–lower lip curve contour line from the frontal view. (A) The contour line is interrupted (arrow) in the nasal base area, indicating maxillary anteroposterior deficiency. (B) The improvement in the continuity of the contour of the patient in (A) is evident after maxillary advancement. The contour line forms a smooth continuous contour without interruptions. (C) There is a double break in the contour line in this patient. The interruption of the line in the nasal base area (top arrow) indicates maxillary anteroposterior deficiency, and in the lower-lip area, the interruption of the line (bottom arrow) is ahead of the curve, indicating mandibular anteroposterior excess. (Reyneke 2012)***

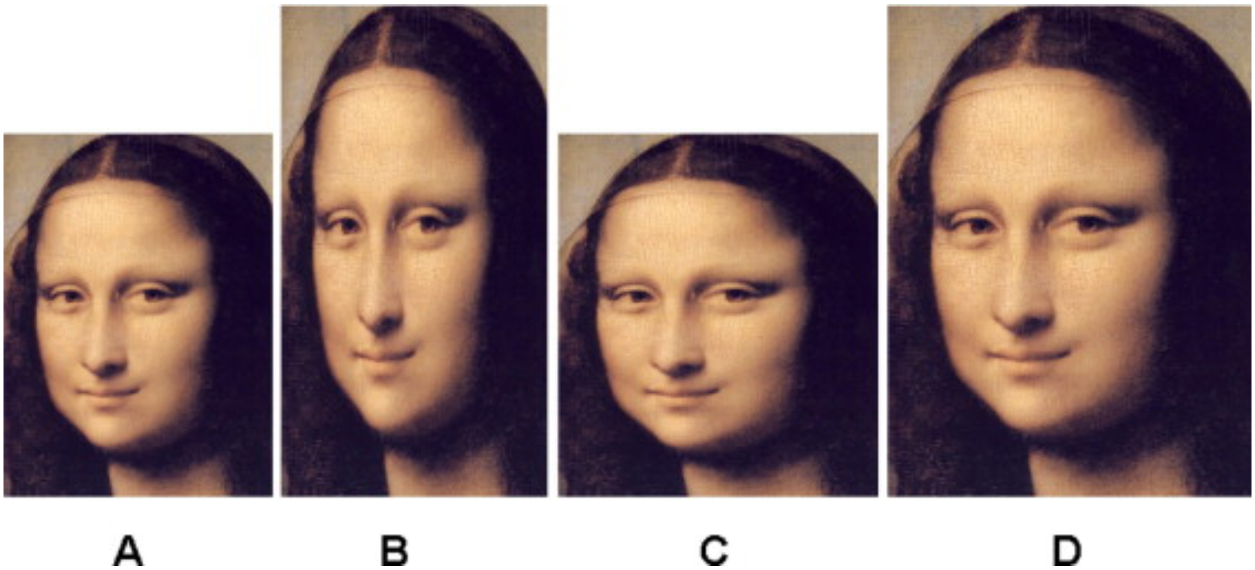

Figure 5 ***The concept of facial proportions is illustrated by digitally modifying a face considered to have ideal facial proportions (Mona Lisa—Leonardo da Vinci [1452-1519]). (A) The face shows a harmonious balance between the vertical and horizontal dimensions. (B) The transverse dimension is maintained, but the vertical one is increased with obvious loss of proportion. (C) Maintaining the vertical but increasing the transverse dimension also leads to loss of facial proportion. (D) By an equal increase of the transverse and the vertical dimensions, facial proportion is reestablished. The importance of proportion between facial parameters and the error of relying on absolute values is clearly illustrated. (Reyneke 2012)***

1.4.2 Profile view (Figures 6-9):

The patient's head should be in a natural head posture with the lips relaxed (Arnett 1993).

a. Evaluate the nasolabial angle which should ideally measure from 85-105 degrees from the columella of the nose to the most anterior portion of the upper lip (Reynak 2012). Excessive retraction of the upper incisors will result in less upper lip tissue support and an aesthetically unpleasant nasolabial angle.
b. Evaluate the labiomental angle which should ideally be 120 +/- 10 degrees when measuring from the most anterior/inferior portion of the lower lip and the pogonion. This angle will become more acute in severe class II patients or those with macrogenia. This angle will become more obtuse in class III patients with retroclined mandibular incisors or those with microgenia.
c. Evaluate lip-chin-throat angle as well as the chin-throat length. An aesthetic lip-chin-throat angle is between 100-120 degrees and 38-48mm, respectively.
d. Evaluate facial contour angle, classifying the face as convex, flat or concave. The measurement is from soft tissue glabella to subnasale to pogonion. The aesthetic angle for females is -13 +/- 4 degrees (convex) and -11 +/- 4 degrees for male (convex). Other facial aesthetic research has shown when the facial form is evaluated from the profile view, that a straighter profile is preferred for men and a more convex profile for women (Czarnecki 1993). This angle can be influenced with clockwise or counterclockwise rotation of the mandible, a result of orthodontic dental movement or maxillary vertical skeletal growth.
e. Allows proper examination of the upper and lower lip relationship. In females, it is aesthetically desirable to have a more prominent upper lip compared to the lower lip. Also, the lower lip should be slightly anterior to the chin in an anterior-posterior projection. In males, the aesthetic opinion is to have equally proportioned lips and at the same A-P position as the chin.

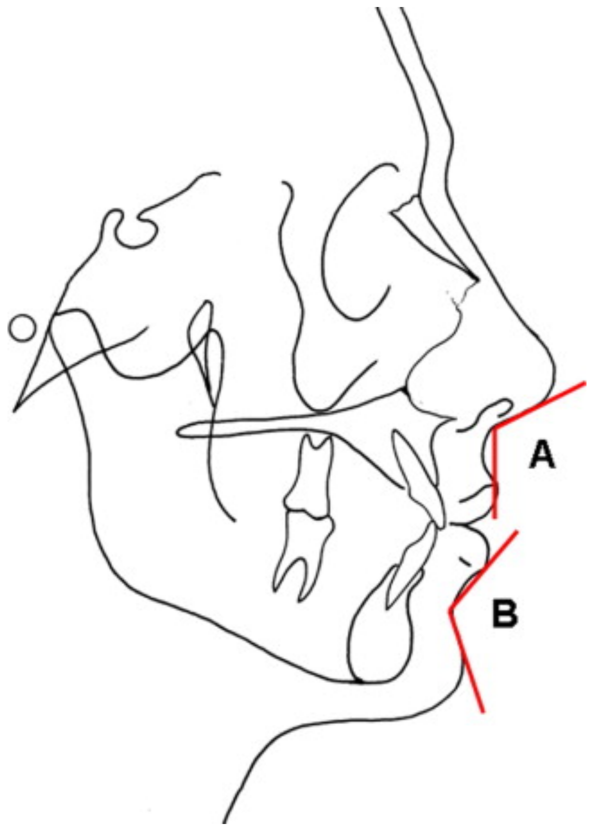

Figure 6 ***(A) The nasolabial angle, measured between the columella of the nose and the upper lip, should be 85-105 degrees. Poor support of the upper lip by the incisors (excessive orthodontic retraction of the upper incisors) or a hanging columella will result in an obtuse angle, whereas this angle will be acute in Class III cases or in patients with overclosed bites. (B) The labiomental angle is formed by the lower lip and chin tangent. The angle will be acute in patients with Class II malocclusion and increased overjet or macrogenia, whereas it will be obtuse in patients with Class III malocclusion and/or microgenia. (Reyneke 2012)***

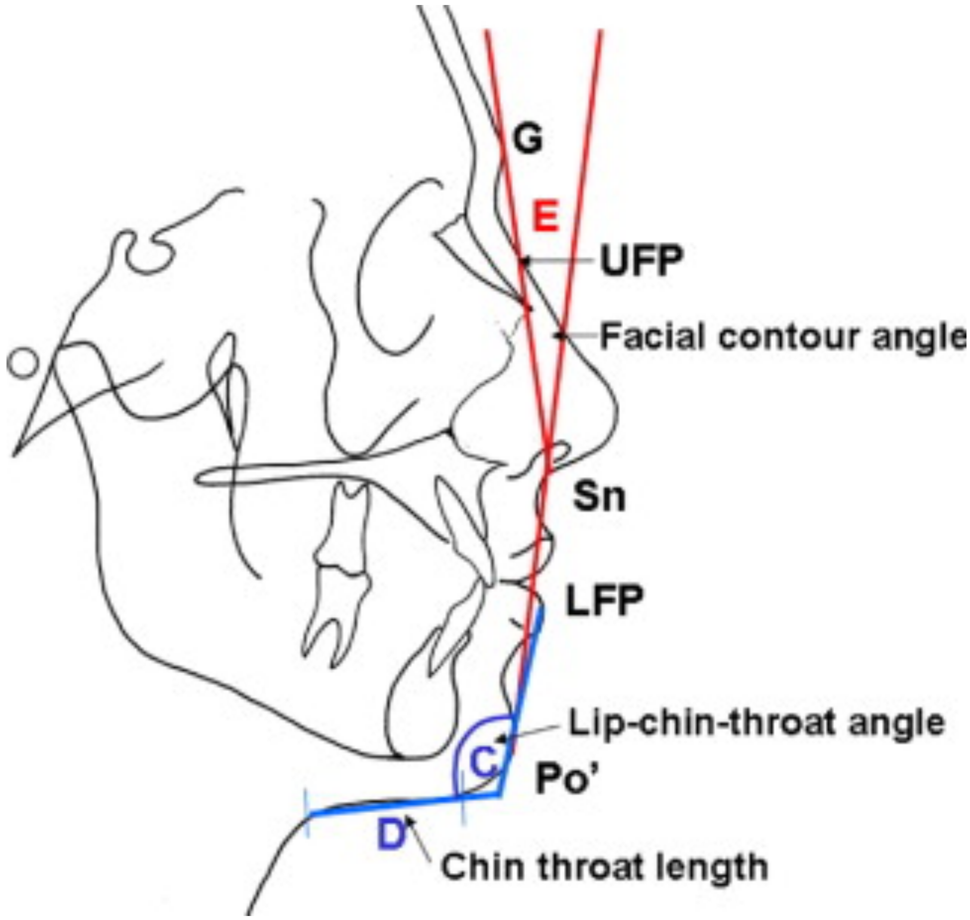

Figure 7 ***The lip–chin–throat angle (C) is measured between the lower lip and the submental tangent and should be ±110 degrees. The angle will be obtuse in patients with microgenia, excessive submental adipose tissue, and protrusive lower incisors, whereas it will be acute in Class III cases and patients with macrogenia. The chin–throat length (D) can be measured from the chin–throat angle to the soft-tissue menton. The approximate length should be 42 ± 6 mm and will be longer in Class III cases and shorter in Class II cases. The facial contour angle (E) is formed by the upper facial plane (UFP) by connecting glabella (G) to subnasale (Sn) and the lower facial plane (LFP) by connecting subnasale (Sn) to soft-tissue pogonion Po'. It is deemed as negative if the LFP is ahead of the UFP and positive if the UFP is ahead of the LFP. Males tend to have a straighter profile (−11 ± 4 degrees), and a more convex profile is considered esthetically pleasing for females (−13 ± 4 degrees). (Reyneke 2012)***

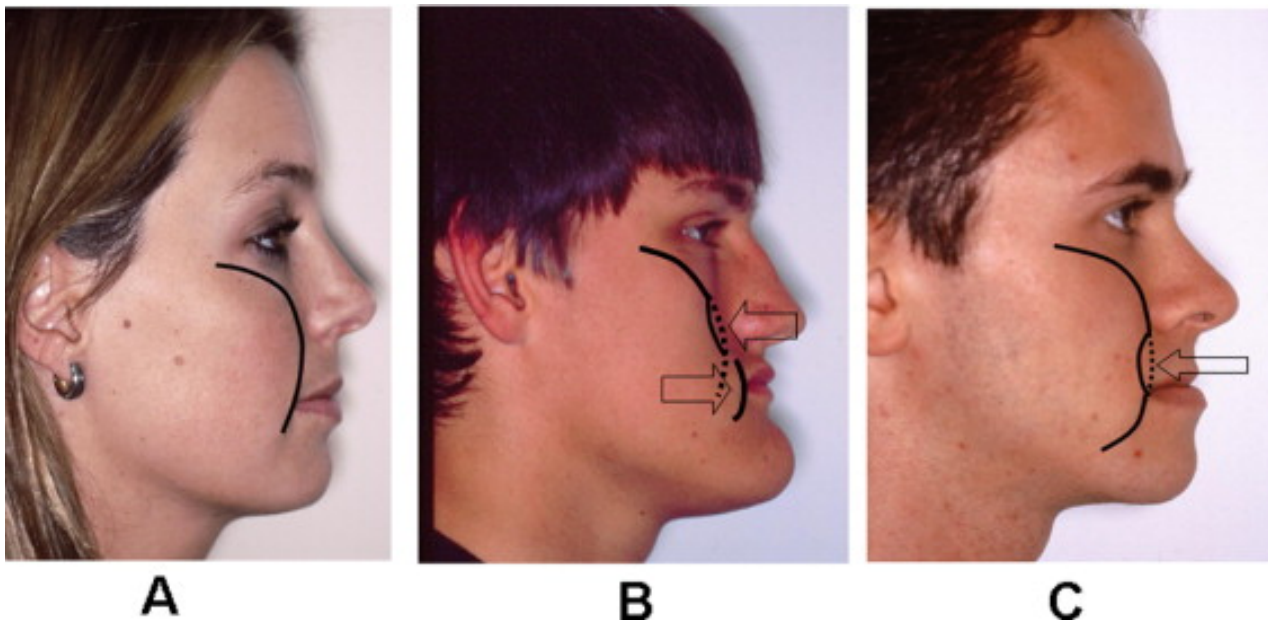

Figure 8 ***The cheekbone–nasal base–lip curve contour line in the profile view. (A) The contour line forms a smooth continuous curve without interruptions in an individual with a well-balanced facial profile. (B) The curve is interrupted in 2 places. The concavity in the upper-lip area suggests maxillary anteroposterior deficiency (top arrow), whereas the lower end of the curve is further forward than it should be, suggesting mandibular anteroposterior excess (bottom arrow). (C) The curve is interrupted in the upper-lip area, indicating maxillary anteroposterior deficiency. The curve is continuous at the lower end, indicating that the mandible is in harmony with the rest of the face. (Reyneke 2012)***

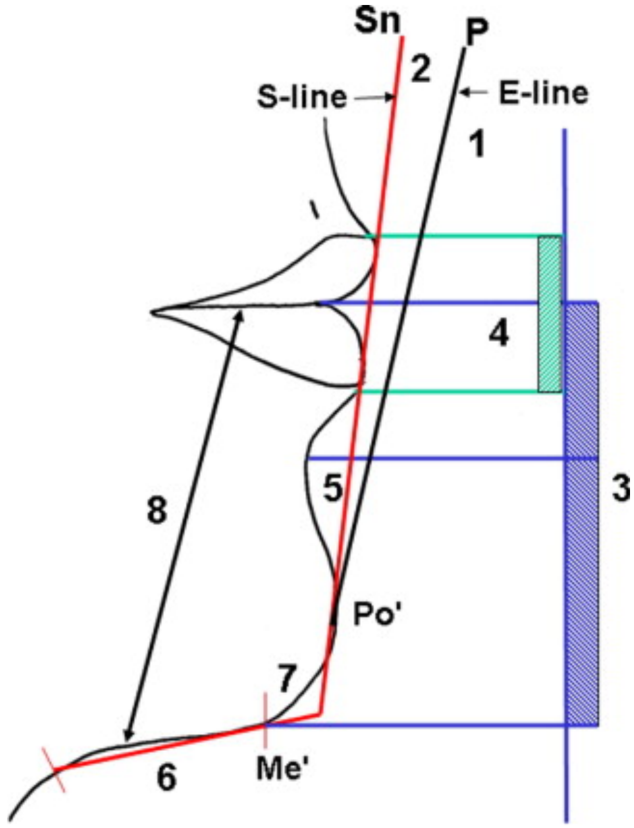

Figure 9 ***Esthetic evaluation of the lips and chin. (1) The E-line is drawn from pronasale (P) to soft-tissue pogonion (Po). The upper lip should be 4 ± 2 mm behind the line, and the lower lip should be 2 ± 2 mm behind the line. (2) The S-line is drawn from the midpoint of the S-shaped curve between pronasale (P) and subnasale (Sn) to soft-tissue pogonion (Po), and both the lips should fall on the line. These lines are good indicators of chin prominence, nasal projection, mandibular anteroposterior position, and lip prominence or flatness. (3) The height of the chin is measured from stomion to soft-tissue menton and the distance should be 40 ± 4 mm for females and 42 ± 4 mm for males. (4) The lower-lip vermillion is 25% more exposed than the upper-lip vermillion. (5) The depth of the labiomental fold should divide the chin into an upper third and lower two-thirds. (6) The chin–throat length is measured from the angle of the throat to soft-tissue menton. The distance should be approximately 42 ± 6 mm and is an indication of mandibular length. (7) Lower lip–chin–throat angle is contained between a line drawn from the lower-lip vermillion to soft-tissue pogonion and a submental tangent. An angulation of 110 ± 8 degrees is considered normal. (8) The soft tissue of the chin should form a smooth harmonious curve. (Reyneke 2012)***

1.5 3D STEREOPHOTOGRAMMETRY IMAGING

Recent advances in imaging technology have made available 3D photography for the use of facial form analysis. Three-dimensional (3D) soft tissue imaging allows the capture of surface tissue in three dimensions, overcoming the limitations of two-dimensional analysis by providing enough information for the analysis of all the facial components (Souccar 2012). This capture of surface tissue is not dependent on proper head position and/or camera orientation (Ferrario 1996). There are several modalities of 3D soft tissue capture and analysis, with photogrammetry and laser scanners being the two most popular and widely used (Hennessy 2005). Both systems use multiple cameras to capture illuminated objects, are non-invasive and without objecting the patient to radiation (Hennessy 2006). Laser scanners triangulate soft tissue form using geometric principles with the use of a light source, the object being measured, and a receiver. The laser beam reflects scattered light off of the target, which is recorded by the receiver, ultimately analyzing the object's spacial location (Blais 2004). Stereophotogrammetry also uses triangulation, utilizing mathematical algorithms to analyze points captured from a light mesh projected on the object being measured. A minimum of two cameras in a stereo pair with a known focal length in relation to the patient are needed to accurately formulate the shape of the object. These cameras at different angles to the object overlap the different light patterns reflected from the object, allowing a continuous 360-degree 3D image of the object (Lane 2008). The stereophotogrammetry system has a much faster capture time (1 second), an accuracy of approximately 0.5mm, a resolution of 40,000 polygons, a 24-bit color image, and does not need the patient to close eyes for risk of damage from a laser beam. These factors make the stereophotogrammetry system the ideal method for facial form capture, particularly in younger patients that are difficult to keep still (Honrado 2004, Souccar 2012).

Two methods for the examination of the 3D image are a) millmetric/angular/volumetric measurements between operator appointed landmarks and b) the use of facial averages to examine facial natural development and orthodontic/surgical treatment changes (Souccar 2012). Landmark placement for the use of facial measurement with the 3D stereophotogrammetry system has been shown to be precise, repeatable, and accurate for soft tissue analysis (Aldridge 2005). The drawback of this technique is the limited number of identifiable landmarks. In contrast, the facial averages method superimposes two captured images using stable and identifiable landmarks, allowing linear measurements and surface volumetric evaluation between the two objects (Zhurov 2010).

Furthermore, 3D surface imaging has been used to isolate specific diagnostic traits in craniofacial syndromic populations. Identifying specific diagnostic facial markers, for example in Fetal Alcohol Syndrome or non-syndromic cleft lip/palate, aids in the rapid screening and identification of affected populations (Douglas 2010).

1.6 AIM OF THIS STUDY

The aim of this pilot study is to study the difference of 3D photography versus 2D photography for facial form analysis to determine which photographic method most closely mimics clinical analysis of facial form. Through our photographic and clinical facial form evaluations, the aim is to a) compare candidate facial form analysis from 2D photographs to clinical facial form analysis in the 12 mentioned facial form criteria b) compare candidate facial form analysis from 3D photographs to clinical facial form analysis in the 12 criteria c) compare the differences between 3D and 2D facial form analysis when compared to clinical facial form analysis in the 12 criteria, d) evaluate facial form analysis (2D, 3D, and Clinical) of the 12 criteria between the two evaluators, E) evaluate consistency of facial form analysis (2D, 3D, and Clinical) of the 12 criteria by each evaluator within each medium used. Ultimately, the hope is to add to the body of knowledge for using the 3-D Stereophotogrammetry system in evaluating facial form and also improving upon the facial form diagnosis process, which every orthodontist undergoes with each patient.

1.7 HYPOTHESIS

We hypothesize that facial form diagnosis using 3D photographs more closely match clinical facial form diagnosis when compared to using 2D photographs. We further hypothesize a high reliability of facial form diagnosis between the two evaluators using the same medium of 2D photographs, 3D photographs or clinical evaluation. Lastly, we hypothesize a high reliability of facial form diagnosis within the same raters using the three different mediums.

2.0 METHODS

This research study was credentialed by the University of Pittsburgh Health Sciences and approved by the University of Pittsburgh Institutional Review Board. University of Pittsburgh dental and dental hygiene students were recruited for this research project, none of whom were below 18 years of age. This population was targeted for potential candidates because dental and dental hygiene students were easily accessible within the dental building, in high numbers, and anticipated to be willing and eager to participate in dental related research. Also it was unlikely that the two orthodontic faculty evaluators had much, if any, contact with the potential candidates, which helped with candidate anonymity. Lastly, this group of potential candidates could have been the typical patient pool seen in an orthodontic clinic.

2.1 CANDIDATE RECRUITMENT

Candidate recruitment was conducted by Payam Zamani, DDS, a third-year University of Pittsburgh orthodontic resident, in the dental school building. Dr. Zamani presented a 5-minute PowerPoint presentation to the dental and dental hygiene students in one of their regular lectures (acquired permission by course professor) on the advances of facial imaging and 3D imaging and why it is important for orthodontic diagnosing and treatment planning. Any interested candidates were asked to email the orthodontic resident to be scheduled for a screening.

All efforts were taken to assure recruitment did not have undue influences on the potential candidates. It was stressed to the potential candidates that participation is completely voluntary and their only benefit for participation is knowledge that they are advancing scientific research and they will be able to experience the process of facial form diagnosing and 3D imaging, tools which might help them in their future practices.

2.2 CANDIDATE CONSENT

Every potential candidate was required to review and sign an informed consent form. The informed consent form was given to the potential candidate prior to any screening protocols or 3D/2D photography. Candidates were told, "Your participation is completely voluntary and there will be no negative repercussions if you decline to participate. You will not be compensated in any way. You may read the consent form now and I can answer any questions you may have. We can begin the screening process today or you may take up to one week to decide if you will like to participate in the study" to ensure there is no coercion or undue influence. As for the orthodontic evaluators, Dr. Zamani obtained verbal consent from the evaluators. The orthodontic faculty evaluators were given up to two weeks to decide to participate in the study.

Study candidates were first asked to read and sign the informed consent form, which outlined the research process, what was expected of them and how we may utilize research information in terms of data publication. Dr. Zamani was responsible for explaining and documenting candidate consent forms. Dr. Zamani clearly answered any questions regarding the consent form and the expectation of the candidates and also outlined the process of the research study, including photos, facial evaluations, and general timeline. Candidates had one week after they were handed the consent form and explained the process of the research study to determine if they wanted to join the study. They were asked to email Dr. Zamani with their decision. As for the orthodontic faculty evaluators, Dr. Zamani read to the potential examiners a recruitment script. As stated in the script, the evaluators had up to two weeks to decide to participate in the project. Dr. Zamani answered any questions regarding the verbal consent form and the expectation of the candidates and outlined the process of the research study, including evaluating photos, facial evaluations, and general timeline of the project.

2.3 INCLUSION AND EXCLUSION CRITERIA

The inclusion criteria for candidates included dental and dental hygiene students who were at least 18 years of age. All types of facial forms were accepted into the study.

The exclusion criteria included any facial trauma, swelling, scars, large visible acne, which could have changed in appearance within the three months post photograph capture. Also, those who planed to undergo facial altering like facial injectables, surgery and/or microabrasion in the 3 months needed for facial form evaluation were excluded from the study. Also, those who were currently in orthodontic treatment were excluded from the study. Any candidate who experienced any of these facial soft tissue alterations mid-study were also excluded.

2.4 PHOTOGRAPHIC RECORDINGS

Candidates who were accepted into the study had 3D full facial and 2D frontal and profile photographs taken in the repose position. Candidates were asked to shave or shortly trim any facial hair and to not use facial makeup in order to ensure consistency of facial form between the 2D, 3D and clinical evaluations and also allow the 3D camera to capture the proper skin tone of the candidates. Candidates had a bite registration taken before any recordings to insure the position of the mandible and occlusion remained constant throughout the photographic recordings and evaluations. Candidates were asked to wear large black sunglasses covering the eyes and a black head beanie covering the hair to insure subject anonymity. Candidates were asked to lick their lips, softly bite into their pre-registered bite registrations, and to relax their facial muscles/face for the picture. One operator took all of the 3D and 2D photographs and each candidate had the 3D and 2D photos taken at the same session to prevent any facial changes. All 3D and 2D photographs were taken in the basement 3D camera room in the dental school.

2.4.1 3dMDface Digital Stereophotogrammetry

The 3D images was taken using a 3dMDface digital stereophotogrammetry system at the University of Pittsburgh School of Dental Medicine building. The system was pre-calibrated at the measured focal point and on a fixed tri-pod stand. This validated system is capable of acquiring the geometry and skin texture of the facial surface in less than 1 second. All subjects were seated four feet away from the 3dMDface digital camera system and patients were asked to be in the natural head posture facing straight between the cameras, as it is a reproducible position as the picture is taken (Chiu 1991). Multiple 3D photographs were taken if the rendering of the original photograph resulted in empty spaces on the soft tissue as a result of improper lighting on the skin from the flash. A white screen was the background for all 3D photographs.

2.4.2 2D Digital Photography

The photographic set-up included a PowerShot A2400 IS HD Canon 16.0 megapixel 5x optical zoom digital camera. The camera was on “portrait” mode with flash off to eliminate any shadowing effect. The camera was held five feet from a marked line where the candidates were asked to stand. All effort was taken to maintain the horizontal optical axis of the lens. Candidates were asked to stand on the drawn line on the floor and face forward (frontal picture) and turn the entire body to the left (profile picture) in the natural head position outlined in Chiu 1991. A white screen was the background for all 2D photographs.

2.5 EVALUATORS

The evaluators were two orthodontic faculty members at the University if Pittsburgh School of Dental Medicine. Evaluator #1 (D.M.D., M.D.S., Ph.D.) and evaluator #2 (D.M.D., M.S.) were both ABO certified orthodontist and assistant professors at the University of Pittsburgh department of Orthodontics and Dentofacial Orthopedics. Evaluator #1 has 25 years of private practice experience as well as 20 years in academics. Evaluator #2 has 30 years in private practice experience and 5 years in academics. The evaluators did not have ties of any kind to the subjects being evaluated. One evaluator did not have any tie to the current research project while the other was asked to be on the research project masters committee. However, this evaluator did not have any specific knowledge of any project details until after the evaluations were complete. No compensation of any kind was given to the evaluators.

2.6 EVALUATIONS

Evaluations were conducted in the orthodontic department of the school of dental medicine. All evaluations were conducted in a private orthodontic conference room. Evaluators were not given any information on the candidates except that they were a dental or dental hygiene student. Evaluators analyzed 12 categories of facial form of the subjects using a continuous scale of 1-10. These 12 categories were chosen because they are the most used measurements at the University if Pittsburgh orthodontics department and they also encompass most of the main facial form categories previously mentioned. The 12 different categories of facial form can be seen in Figure 10.

FACIAL FORM EVALUATION

Evaluators Name:

Date:

Session #:

For each item identified below, circle the number to the right that best fits your judgment of facial form.

	RETRUSIVE				WNL					PROTRUSIVE
1. Upper lip procumbency in the Anterior-Posterior plane	1	2	3	4	5	6	7	8	9	10
2. Lower lip procumbency in the Anterior-Posterior plane	1	2	3	4	5	6	7	8	9	10
3. Overall lip procumbency in the Anterior-Posterior plane	1	2	3	4	5	6	7	8	9	10
4. Mandibular position in the Anterior-Posterior plane	1	2	3	4	5	6	7	8	9	10
5. Maxillary position (malar fullness) in the Anterior-Posterior plane	1	2	3	4	5	6	7	8	9	10

	ACUTE				WNL					OBTUSE
6. Nasolabial angle	1	2	3	4	5	6	7	8	9	10
7. Labiomental angle	1	2	3	4	5	6	7	8	9	10

	PATIENT'S RIGHT				CENTERED					LEFT
8. Mandibular body deviation (asymmetry of the mandibular body)	1	2	3	4	5	6	7	8	9	10
9. Chin deviation (asymmetry of the chin)	1	2	3	4	5	6	7	8	9	10
10. Nose deviation (asymmetry of the nose)	1	2	3	4	5	6	7	8	9	10

	NOT PRESENT									PRESENT
11. Mentalis muscle strain	1	2	3	4	5	6	7	8	9	10

	SHORT				WNL					LONG
12. Lower 1/3 facial height (subnasale to menton in relation to the middle facial third –glabella to subnasale)	1	2	3	4	5	6	7	8	9	10

Figure 10 Sample evaluator questionnaire showing the 12 categories of facial form

2.6.1 3D Evaluation

Evaluators were given a 5-minute tutorial by Dr. Zamani to demonstrate how to control facial movement on the laptop screen (rotation/tipping of the face) using a sample model as well as to give instructions for this segment of evaluation. 3D full facial digital photographs of each candidate were shown on a computer laptop screen (property of the school of dental medicine) that allowed the evaluator to view the face from all angles at the operators' control. The 3D photographs were available to analyze for the above-mentioned 12 criteria for a maximum of 2 minutes. The evaluators were given the option to choose to rate each category at the end of the 2 minutes or within their allotted time for facial analysis. The evaluations by the two evaluators were conducted simultaneously in the same room. Each evaluator sat on either side of the operator, Dr. Zamani. The operator would display the next 3D photograph upon the request of both evaluators.

2.6.2 2D Evaluation

The 2D facial and profile photographs were displayed on a PowerPoint presentation. The 2D photographs were available to analyze for the above-mentioned 12 categories for a maximum of 2 minutes. The operator were given the option to choose to rate each category at the end of the 2 minutes or within their allotted time for facial analysis. The evaluations by the two evaluators were conducted simultaneously in the same room. Each evaluator sat on either side of the operator, Dr. Zamani. The operator would display the next 2D photograph upon the request of both evaluators.

2.6.3 Clinical Evaluation

Candidates were seated in a private orthodontic room wearing the same clothing/sun glasses, head beanie as the previously taken 2D/3D photographs. Candidates were given the same instructions as before (bite registration, repose face, etc.), they were asked to not open their mouth, speak, or change their facial expression and were seated in front of a white screen to mimic a similar background to the 2D and 3D photos. They were allowed to move their head side to side and up and down, per the evaluators request. Evaluators were not permitted to touch the candidates. The candidates were available to be analyzed for the above-mentioned 12 categories for a maximum of 2 minutes. The operator were given the option to choose to rate each category at the end of the 2 minutes or within their allotted time for facial analysis. The evaluations by the two evaluators were conducted simultaneously in the same room.

2.7 STATISTICAL ANALYSIS AND STUDY DESIGN RANDOMIZATION

The subjects were photographed in a random order based on the subject's schedule. The order in which the evaluators had the opportunity to evaluate each subject's 3D photographs, 2D photographs, and the clinical facial form analysis was also randomized for all subjects using a random number generator on http://graphpad.com/quickcalcs/randomN1.cfm. The order in which the evaluators evaluated via each medium was also random using the same random number generator. In order to insure evaluators did not memorize/remember patient soft tissue form between evaluations sessions (in addition to having each subject cover their eyes and hair), each evaluation session was separated by a 24-hour time span.

To analyze intra-rater reliability, two extra evaluation sessions were conducted for the 2D, 3D and clinical evaluations. These subjects were chosen randomly and the evaluations were conducted under the same protocol and scheduling as the original evaluation sessions.

Intra-rater and inter-rater reliability testing was conducted using Krippendorff's Alpha-Reliability test. A measure is said to have a high reliability if it produces similar results under consistent conditions; in other words, reliability is consistency (Eisinga 2012). Intra-rater reliability is the degree of agreement among repeated tests performed by a single rater and inter-rater reliability is the degree of agreement among raters. We followed Landis and Koch's (1977) guidelines for interpreting reliability values, with values from 0.0 to 0.2 indicating slight agreement, 0.21 to 0.40 indicating fair agreement, 0.41 to 0.60 indicating moderate agreement, 0.61 to 0.80 indicating substantial agreement, and 0.81 to 1.0 indicating almost perfect or perfect agreement. Any negative alpha values in the results indicate evaluator disagreement and *Error* indicates to variability within the evaluators analysis; and therefore, reliability could not be calculated

2.8 PRACTICE TRIAL

In order to train the orthodontic evaluators with the evaluation process and time-line of this project, a practice trial was conducted consisting of five 2D, 3D and clinical evaluations. The evaluators received a 15-minute PowerPoint presentation on facial form analysis and pictures to clearly define what the 12 categories specifically measure. They also received a verbal lesson on the outline of the project. The results of the practice trial are included in the final statistical analysis.

3.0 RESULTS

A total of 77 candidates were recruited and met the inclusion criteria for this study and no candidates were excluded once the study commenced. All candidates had 2D and 3D photographs taken. Due to concerns of evaluator fatigue, 54 candidates were randomly chosen from the group of 77 to be included in the study. This group consisted of 21 males and 33 females. In addition to the three practice evaluations, there were a total of nine evaluation sessions: Clinical 54 candidates, 2D 54 candidates, 3D 54 candidates; 2 times of Clinical 12 candidates, 2D 12 candidates, 3D 12 candidates. The purpose of the 12 candidate evaluation sessions was for intra-rater reliability testing and they were randomly selected from the 54 candidates. The nine evaluation sessions were spread over two-weeks with the order of evaluation type and candidate order within each evaluation session chosen randomly. The evaluation form was grouped from the 1-10 continuous scale to an ordinal scale of 1-3, 4-6, and 7-10.

3.1.1 Intrarater Reliability

Krippendorff's Alpha was used to analyze intra-rater reliability (Tables 1 and 2) following Landis and Koch's (1977) guidelines for interpreting reliability values; values from 0.0 to 0.2 indicating slight agreement, 0.21 to 0.40 indicating fair agreement, 0.41 to 0.60 indicating moderate agreement, 0.61 to 0.80 indicating substantial agreement, and 0.81 to 1.0 indicating almost perfect or perfect agreement. As shown in Table 1, Examiner #1 diagnosed nine out of the total 36 possible categories (12 categories per media) with substantial reliability. These nine are lower lip procumbency, overall lip procumbency, mandibular position in the A-P plane, labiomental angle, mentalis muscle strain, and lower 1/3 facial height. Out of these nine, only category #7 (labiomental angle) was diagnosed with substantial reliability in all three medias. Examiner #2 diagnosed six substantially reliable and seven perfectly reliable categories out of the total 36 possible (12 questions per media). Out of these thirteen, only category #12 (lower $1/3^{rd}$ height) was diagnosed with substantial reliability in all three medias; however, within Examiner #2's evaluations, categories #3 (overall lip procumbency) and #6 (nasolabial angle) were at least substantially reliable in the live and 3D evaluations, category #7 (labiomental angle) was at least substantially reliable in the clinical and 2D evaluations and category #11 (mentalis muscle strain) was at least substantially reliable in the 2D and 3D evaluations.

Table 1: List of reliable facial form categories rated by each examiner in each of the three medias. Listed categories demonstrate substantial reliability (alpha>0.6) and perfect* reliability (alpha>0.8), N=12, 2 sessions.

Table 1: List of reliable categories

	Categories - Clinical	Categories -2D	Categories - 3D
Examiner #1	2,3,4,7	4,7,11	7,12
Examiner #2	1*,3,6,7,12	7*,11*,12*	2*,3*,6*,11,12

Table 2: Reliability (alpha values) between 2 sessions of each media within Examiner #1 and Examiner #2. NA: negative alpha; ERROR: No variation, alpha can't be computed.

Table 2 Intra-rater reliability between two sessions of each media

Categories	Examiner #1 Clinical	Examiner #1 2D	Examiner #1 3D	Examiner #2 Clinical	Examiner #2 2D	Examiner #2 3D
1	NA	NA	0.34	0.84	0.57	NA
2	0.69	0.30	0.36	0.24	0.00	1.00
3	0.62	0.28	0.42	0.67	ERROR	1.00
4	0.69	0.66	0.23	0.51	NA	0.42
5	0.27	NA	NA	0.03	NA	NA
6	0.50	0.29	0.03	0.61	0.04	1.00
7	0.70	0.60	0.60	0.67	1.00	0.75
8	NA	0.11	NA	0.03	NA	NA
9	NA	0.11	NA	0.03	NA	NA
10	0.19	0.13	0.00	0.00	0.00	ERROR
11	0.04	0.73	0.10	0.42	1.00	0.64
12	0.34	0.37	0.63	0.62	1.00	0.66

AGREEMENT

Perfect (alpha>0.8)

Substantial (alpha>0.6)

3.1.2 Reliability Between Media

Krippendorff's Alpha was used to analyze the reliability between the three different media for both examiners (Table 3). There was no substantial reliability (alpha >0.6) found between Examiner #1 evaluations. There were five substantially reliable values for Examiner #2. However, only three of the five category combinations (Category #11 2D-3D, Category #7 Clinical-2D, Category #12 Clinical-2D) included combinations of both categories that previously demonstrated substantial reliability (Table 2).

Table 3: Reliability (alpha values) between medias within Examiner #1 and Examiner #2.
NA: negative alpha; ERROR: No variation, alpha can't be computed.

Table 3: Reliability between medias by each evaluator

Categories	Examiner #1 Clinical-2D	Examiner #1 Clinical-3D	Examiner #1 2D-3D	Examiner #2 Clinical-2D	Examiner #2 Cliniacl-3D	Examiner #2 2D-3D
1	0.41	0.34	0.38	0.45	0.48	0.6
2	0.39	0.34	0.15	0.5	0.55	0.38
3	0.38	0.2	0.22	0.45	0.59	0.37
4	0.37	-0.1	0.12	0.31	0.28	0.47
5	-0.21	-0.1	0.01	-0.27	-0.24	-0.01
6	0.17	0.22	0.39	0.51	0.49	0.69
7	0.51	0.31	0.57	0.65	0.55	0.66
8	0.12	-0.1	-0.11	0.1	0.19	-0.1
9	0.14	-0.2	0.04	0.14	0.25	-0.1
10	0.25	-0.1	-0.19	ERROR	ERROR	ERROR
11	0.2	0.27	0.25	0.55	0.33	0.68
12	0.34	0.15	0.4	0.63	0.46	0.36

AGREEMENT
Perfect (alpha>0.8)
Substantial (alpha>0.6)

3.1.3 Interrater Reliablity

Lastly, Krippendorff's Alpha was used to analyze the interrater reliability for each media (Table 4). However, there were no substantially reliable results from this analysis.

Table 4: Reliability (alpha values) between two examiners for each media.

Table 4 Interrater reliability of each media between the two evaluators

Categories	Clinical	2D	3D
1	0.39	0.2	0.34
2	0.5	0.25	0.46
3	0.36	0.33	0.49
4	0.13	0.1	0.02
5	0.13	0	-0.13
6	0.24	0.39	0.24
7	0.47	0.52	0.29
8	0.15	0.22	0
9	0.34	0.15	-0.04
10	-0.02	-0.27	-0.05
11	0.28	0.31	0.39
12	0.27	0.39	-0.14

AGREEMENT
Perfect (alpha>0.8)
Substantial (alpha>0.6)

4.0 DISCUSSION

Lower third facial form diagnosis is an integral component of orthodontic treatment planning process. The results of this study indicate an overall low level of facial form diagnosis reliability within evaluators using any of the three media. Examiner #2 demonstrated overall higher reliability in facial form diagnosis when compared to Examiner #1, but still at a low level. The overall low level of reliability could be due to several factors including, but not limited to, inadequate training of evaluators for what exactly was being evaluated and/or evaluator fatigue. Possible solutions for evaluator fatigue could be to reduce the number of categories the evaluators analyze, reduce the number of candidates in the evaluation process, and change the 1-10 scale to a more simple 1-3 scale.

At the University of Pittsburgh department of Orthodontic, 2D photographs are the main media used to discuss and teach facial form diagnosis; 3D cameras are not yet available in the clinic due to their expense and it is not feasible for all residents to evaluate each patient in person (clinical). In our study, the two examiners diagnosed only six out of 24 categories (12 categories per examiner) with substantial reliability using the 2D photographs. Out of these, only categories #7 and #11 were diagnosed with substantial reliability by both examiners. This questions the appropriateness of using 2D photographs in facial form diagnosis as a teaching tool and for treatment planning. However, diagnosis using clinical analysis and 3D photographs did not result in much more reliable categories (nine out of 24 categories for clinical and seven for 3D photography) which questions the value of facial form diagnosis with any of the three media.

Clinical evaluations resulted in higher overall numbers of reliability when compared to 3D and 2D photographic evaluations. The two examiners diagnosed seven of the categories with substantial reliability using 3D photographs, six of the categories using 2D photographs and nine of the categories using clinical evaluations. This result supports our initial expectation for the clinical evaluation to be the gold standard because it demonstrated the most categories diagnosed with substantial reliability. However, the examiners still only diagnosed nine out of 24 categories (12 categories per examiner) with substantial reliability using 3D photographs, which makes clinical evaluations an imperfect system for facial form diagnosing. This information is particularly useful for a private practice orthodontist who could rely on clinical evaluations for facial form diagnosis and treatment plan. As mentioned above, this is not the case in an educational setting.

Krippendorff's Alpha inter-rater reliability analysis was used to evaluate diagnosis similarities between the two evaluators. Facial diagnosing is very subjective for many reasons, including the educational background of the orthodontist, their opinion of aesthetic beauty and balance, and/or experience in facial form diagnosis. Only categories that both evaluators diagnosed with substantial intra-rater reliability can be used to analyze inter-rater reliability. Category #3 Clinical (overall lip procumbency), #7 Clinical and 2D (labiomental angle), #11 2D (mentalis muscle strain), and #12 3D (lower 1/3 facial height) demonstrated substantial intra-rater reliability by both evaluators. However, when looking at table 4 for inter-rater reliability, none of the categories demonstrated substantial reliability. This finding supports the idea that facial form analysis is a subjective skill and the two evaluators, much like many orthodontists with differing diagnosis, did not agree with each other's analysis.

Lastly, Krippendorff's Alpha reliability testing was used to determine if diagnosis using either 2D or 3D photographs more closely resembled clinical diagnosis. Only categories previously diagnosed with substantial reliability using all three medias were analyzed (Table 2). This resulted in Examiner #2's diagnosis of category #12 (lower 1/3 facial height) and Examiner #1's diagnosis of category #7 (labiomental angle). Based on these results, Examiner #2's 2D diagnosis of lower 1/3 facial height more closely and reliably resembled the clinical evaluation when compared to the 3D evaluation of lower 1/3 facial height (Clinical-2D alpha of 0.63 vs. Clinical-3D alpha of 0.46). Examiner #1's 2D evaluation of the labiomental angle more closely and reliably resembled the clinical evaluation when compared to the 3D evaluation of the labiomental angle (Clinical-2D alpha of 0.51 vs. Clinical-3D alpha of 0.31). However, it is important to note that Examiner #1's Clinical-2D evaluation alpha, although higher than the Clinical-3D alpha, did not meet the >0.6 threshold to be considered substantially reliable. Although 2D photographs are shown here to more closely resemble clinical evaluations when evaluating lower 1/3 facial height and labiomental fold, these are only two of twelve criteria; therefore, it is difficult to conclude facial diagnosis using 2D photography more closely resembles clinical diagnosis than using 3D photographs.

This pilot study had several downfalls that could have affected the results. The two evaluators were provided with five clinical, 2D and 3D practice sessions along with a PowerPoint presentation of the 12 criteria and their exact meaning. It is possible that a more extensive practice session was needed prior to the study. Also, the 1-10 continuous scale, which the evaluators used for diagnosis, was grouped to the ordinal scale of 1-3, 4-6, and 7-10. This was due to the fact that three categories are more clinically applicable than a 1-10 scale. Also, the 1-10 scale could not have been divided into three even groups as the first two groups contained three numbers each (1,2,3 and 4,5,6) and the third group contained four (7,8,9,10). This difference could have ultimately altered the results. A 1-3 categorical scale might have been more appropriate for the evaluation sheet and recommended for future studies. Also, the educational background and/or personal bias of facial attractiveness and norms could have played a large role in the subjective analysis of facial form diagnosis and possibly played a rold in the greater consistency of one evaluator over the other. Lastly, evaluator fatigue could have altered the results. This could easily be solved in a future study by using a smaller sample size, lower number of categories per questionnaire for the evaluators to analyze and a greater timespan between the evaluations.

5.0 CONCLUSION

This project is a pilot study to analyze how orthodontists evaluate and diagnose facial form. Facial form diagnosis is important because it partially dictates the orthodontic treatment plan, which can include extraction of teeth, use of functional appliances or orthognathic surgery to move teeth and facial bones. There are many criteria in the literature for lower 1/3 facial form analysis. We chose the most common 12 criteria to be included in this study. Some orthodontists use none of the criteria for analysis and some use most of them. We were interested to analyze three questions:

1) Can an orthodontist reliably diagnose any of the 12 criteria using the 3 given media of clinical, 2D photography and 3D photography?
2) Does 2D or 3D photography provide more diagnosis similarities to clinical evaluation of facial form?
3) Can the two evaluating orthodontists have similar facial form diagnosis results?

The results indicated the two examiners did not reliably diagnose most of the 12 facial form categories using the three media. Because of the low intra-rater reliability for the 12 categories within the two orthodontists, it is difficult to properly answer questions 2 and 3.

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