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Three-dimensional soft tissue changes upon smiling

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Three-dimensional soft tissue changes upon smiling

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

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<u>Abstract</u>

THREE-DIMENSIONAL SOFT TISSUE CHANGES UPON SMILING

By Clayton H. McEntire, D.M.D.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2013

Thesis Director: Steven J Lindauer, D.M.D., M.Dent.Sc.
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As esthetic improvement continues to be a primary goal of orthodontic patients and practitioners, it is important to understand the soft tissue movements that occur during the transition from rest to smile. Advances in technology allow capture of 3-dimesional photographs. The purpose of this study was to quantify the soft tissue changes that occur upon smiling and to compare changes between males and females using 3-dimensional photography. Fifty-four participants had resting and smiling photographs taken with the 3dMDface camera system. The two images were registered on stable facial surfaces, landmarks were placed, and measurements were recorded. Three-dimensional changes occurred in the following regions of the face in both males and females: eyes, ears, nose and lips. Intercommissure width of the lips was shown to increase more in females than males, but males showed increased mobility in landmarks at the base of the nose.

Introduction

The majority of patients seeking orthodontic treatment present for improvements in the appearance of their teeth and overall smile. Because of this, it is the orthodontist's responsibility to have optimally esthetic results as a primary goal and expectation when developing individualized treatment plans for patients. The components of the smile have been previously described: the teeth, gingival scaffold, and lip framework.[1] The American Board of Orthodontics provides a method for case analysis in its Objective Grading System, but none of the numerical values within this systematized assessment provide analysis of soft tissue. Primary focus is on radiographic, inter-arch, and intra-arch dental relationships.[2] Assessment of soft tissue mobility and esthetics is currently a subjective process. Therefore, efforts should be focused on making soft tissue esthetic outcomes more predictable.

Soft tissue expectations are critical in cases where patients present with a chief complaint of excessive gingival display, often referred to as a “gummy smile.” This condition may have negative psychosocial ramifications.[3] Kokich et al surveyed orthodontists and found that greater than 2 mm of maxillary gingiva displayed when smiling is excessive; laypeople and general dentists accepted up to 4 mm.[4] Morley and Eubank described that showing less than 75% of the central incisor on smile is considered inadequate.[5] It has also been demonstrated that a patient’s upper lip resting and smiling position moves coronally during the aging process.[6]

The etiology of excessive gingival display has been characterized by one or a combination of the following variables: vertical maxillary excess, short upper lip (philtrum), extruded maxillary incisors, gingival hyperplasia or delayed passive eruption, or hypermobile smile.[7] Different treatment protocols may be utilitized to meet the treatment objective of reducing gingival display, but the treatment modality selected should be appropriately paired with the applicable etiologic factor. Extruded maxillary incisors might be treated with an intrusion arch.[8] Vertical maxillary excess might require a maxillary impaction surgical procedure or intrusive mechanics via temporary anchorage devices.[9,10] Botox therapy or periodontal lip repositioning procedures have been described as appropriate treatment options for hypermobile lip.[11,12] Skeletal and dental etiologic factors can be identified via cephalometric analysis, but research quantifying soft tissue variations is limited. Miron et al suggested that obtaining accurate averages of soft tissue mobility during the transition from rest to smile is achievable. They performed an analysis of soft tissue changes that occurred from rest to smile as they related to vestibular depth, but some of these measurements were taken in a dynamic, clinical environment where it might be difficult to obtain accurate and repeatable numerical values for each variable.[7]

Other techniques have been used to capture and classify smiling images. Ackerman and Ackerman utilized a Smile-Mesh program to digitally measure smiling pictures.[13] Sarver and Ackerman later proposed that images should be captured using a video camera, assessing the smile in 4 dimensions: transverse, sagittal, vertical, and over time.[14] However, the images that were utilized when taking measurements were 2-dimensional and selected from multiple frames produced from the video file. Two types of smile presentations have been described: the social and enjoyment smiles.[15] A social, or posed, smile is that which one might display for a planned photograph, whereas an enjoyment, or emotional, smile is expressed spontaneously. For studies evaluating smile characteristics, some have chosen to use the enjoyment smile in their methodology, but a social, posed smile has been described as the more repeatable, predictable option.[11,16]

Three-dimensional imaging has opened up new possibilities for evaluating the soft-tissue movements that occur when smiling. Weeden et al utilized video tracking technology to monitor small-diameter reflective markers positioned at standard positions on the face during various movements including maximum smile.[17] 3-D cameras have also been recently implemented to analyze soft tissue differences between 2 time points. Eidson et al utilized the 3dMDface camera system and its associated software to compare facial soft-tissue changes before and after fixed appliance removal.[18] The 3dMDface system captures a 180-degree, ear-to-ear facial image at a speed of 1.5 milliseconds. This is accomplished with 2 sets of 3 cameras at 2 fixed locations with known angulations to the established focal position. As there is overlap of the views from the 2 camera positions, no "stitching" of the images is necessary; instead, a continuous point cloud is produced. The 3dMDvultus software integrates this cloud with the color image and allows image manipulation, registration, and landmarking on a 3 coordinate system from which measurements may be derived. Measurements between landmarks plotted on this system have been shown to be accurate when directly compared to caliper-derived facial anthropometry.[19]

Previous studies have made efforts to quantify the facial changes that occur during the transition from rest to smile,[7,13,17] but further studies are needed to provide repeatable methods to evaluate soft tissue mobility which will aid our ability to identify soft-tissue etiologic factors of excessive gingival display in the future. The purpose of the current study was to quantify the soft tissue movements in 3 dimensions that occur during the transition from rest to smile in young adult males and females. Additionally, the null hypothesis that there is no difference in soft tissue mobility when smiling between males and females was tested.

Materials and Methods

Participants and Image Capture

Approval for this investigation was obtained from the Institutional Review Board of Virginia Commonwealth University (VCU). Students between 20 and 35 years of age were recruited from the VCU School of Dentistry to participate. Exclusion criteria included current orthodontic treatment or a history of maxillofacial surgery including orthognathic or facial plastic surgery of any kind. 24 males and 30 females who met the inclusion criteria volunteered to have 3-dimensional photographs taken in the VCU Department of Orthodontics Craniofacial Imaging Center. Informed consent was obtained from each participant prior to capturing two standardized images, one at rest and another smiling, using the 3dMDface stereo camera system (3dMD, Atlanta, GA).

Prior to each photographic session, the system was calibrated per manufacturer instructions. Participants were seated with their entire heads positioned in the fixed focal field of the camera. If necessary, hair was fixated to allow maximum visualization of the ears and forehead. Participants were instructed to look at a fixed point directly in front of their eyes to allow for maintenance of a natural head position during image capture.[20] Two pictures were taken: one at rest and one smiling. Instructions prior to resting image capture included, "Say 'Emma,' relax, and try not to blink." Smiling picture instructions included, "Smile big as you would for a picture, and try not to blink."

The two images were then registered (superimposed) on one-another using a best fit method described by the software manufacturer (3dMD Vultus) following selection of surfaces that were predicted to remain unchanged between the 2 images: the forehead and upper one-third of the nasal bridge (Figure 1). A root mean squared value (RMS) was recorded from each image that assessed accuracy of the surface superimposition. RMS values of 0.5 mm or less were deemed acceptable, as recommended by the manufacturer. Following successful registration, landmarks were plotted on each image (Figures 2-5, Table I), with “x,” “y,” and “z” (transverse, vertical, and anterior-posterior, respectively) coordinates assigned.[21] These coordinates were then used to measure soft tissue differences between the rest and smiling images in the respective planes of space. Interlandmark distances and multidimensional landmark migration calculations are depicted in Tables II and III.

Nasion was used as a control point as it was located inside of the surface perimeter used for the registrations, and was therefore not expected to show movement from rest to smile. The following inter-landmark measurements along the x axis (transverse) were calculated in millimeters: intercommissure width, nasal width, and interlobular width of the ears. Ocular display and interlabial gap were calculated along the y axis (vertical). Changes in the following points were assessed in the vertical and antero-posterior directions (y and z): nasal tip, subnasal tip, subnasale, inferior philtrum, upper and lower lip midline borders, and right and left commissures.

Table I. Landmarks

Nasion (N) – Deepest point of nasal bridge
Eyelid zeniths (REs, REi, LEs, LEi) – Superior and inferior mid-portion of eyelid margins
Ear lobes (REL and LEL) – Inferior point right and left ear lobes
Nasal Tip (NT) – Most protrusive point of the nose
Lateral borders alar cartilage (RA and LA) – Most lateral point on left and right alar contour
Subnasal tip (SNT) – Inferior border of anterior alar cartilage
Subnasale (Sn) – Mid-point of angle at columella base
Inferior philtrum (IP) – Mid-point of the upper vermillion line
Midline lip borders (UL and LL) – Upper and lower lip inferior/ superior midpoints
Commissures (RC and LC) – Right and left lateral intersection upper and lower lips

Table II. Interlandmark Distances

Ocular display along y axis [(REs – REi) + (LEs – LEi)]/2
Interlobular width of the ears along x axis (RE – LE)
Alar width along x axis (RA– LA)
Intercommissure width along x axis (RC– LC)
Interlabial gap along y axis (UL– LL)

Table III. Multidimensional Changes from Rest to Smile

Nasion movement along x, y, and z axes (N Δ x, y, z)
Nasal tip movement along y and z axes (NT Δ y, z)
Subnasal tip movement along y and z axes (SNT Δ y, z)
Subnasale movement along y and z axes (Sn Δ y, z)
Inferior philtrum movement along y and z axes (IP Δ y, z)
Commissure movement along y and z axes [(RC Δ y+ LC Δ y)]/2 & [(RC Δ z+ LC Δ z)]/2
Upper lip movement along y and z axes (UL Δ y, z)
Lower lip movement along y and z axes (LL Δ y, z)

Figure 1: Image Registration

Figure 2: Landmarks- frontal view

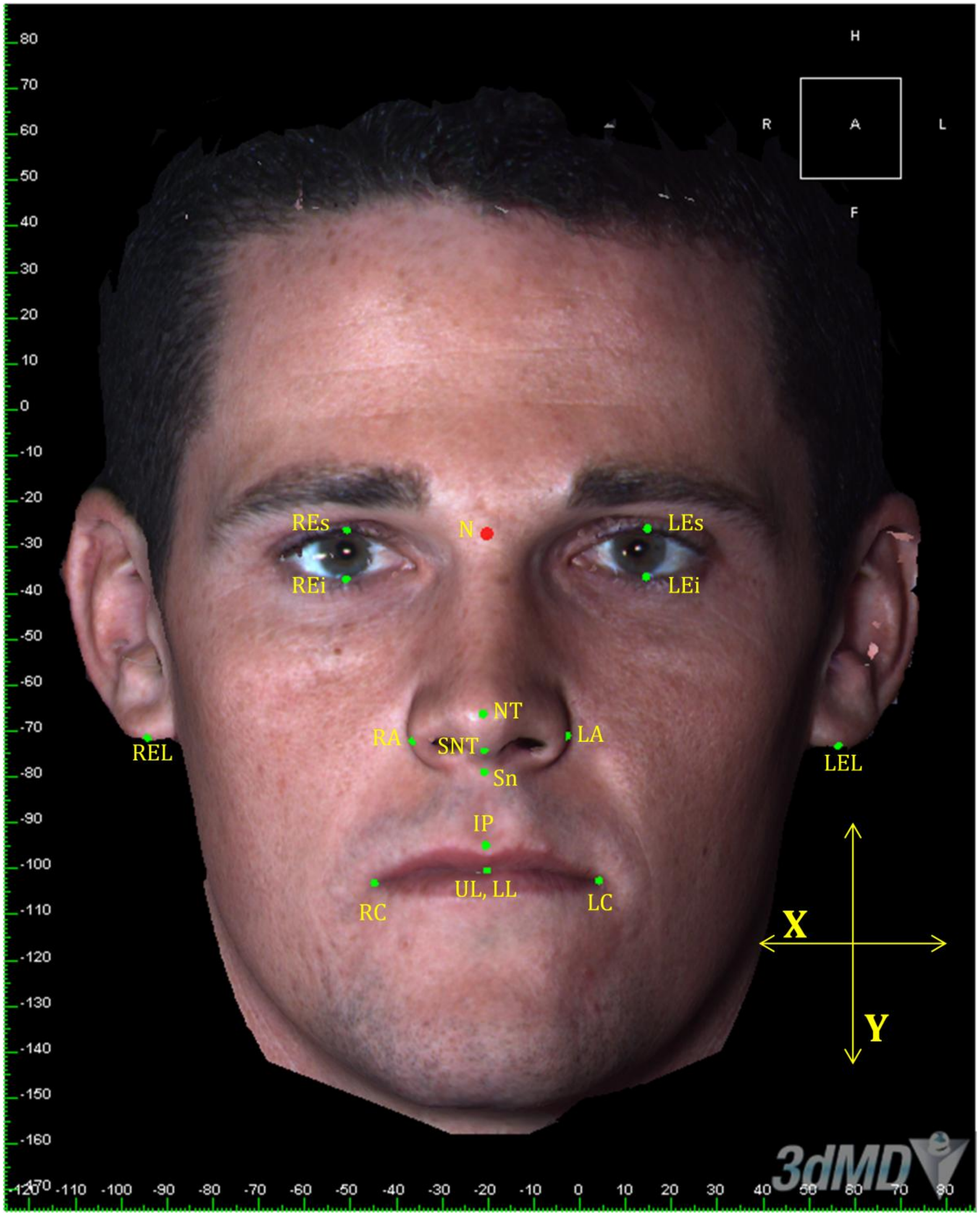


Figure 3: Landmarks- sagittal view

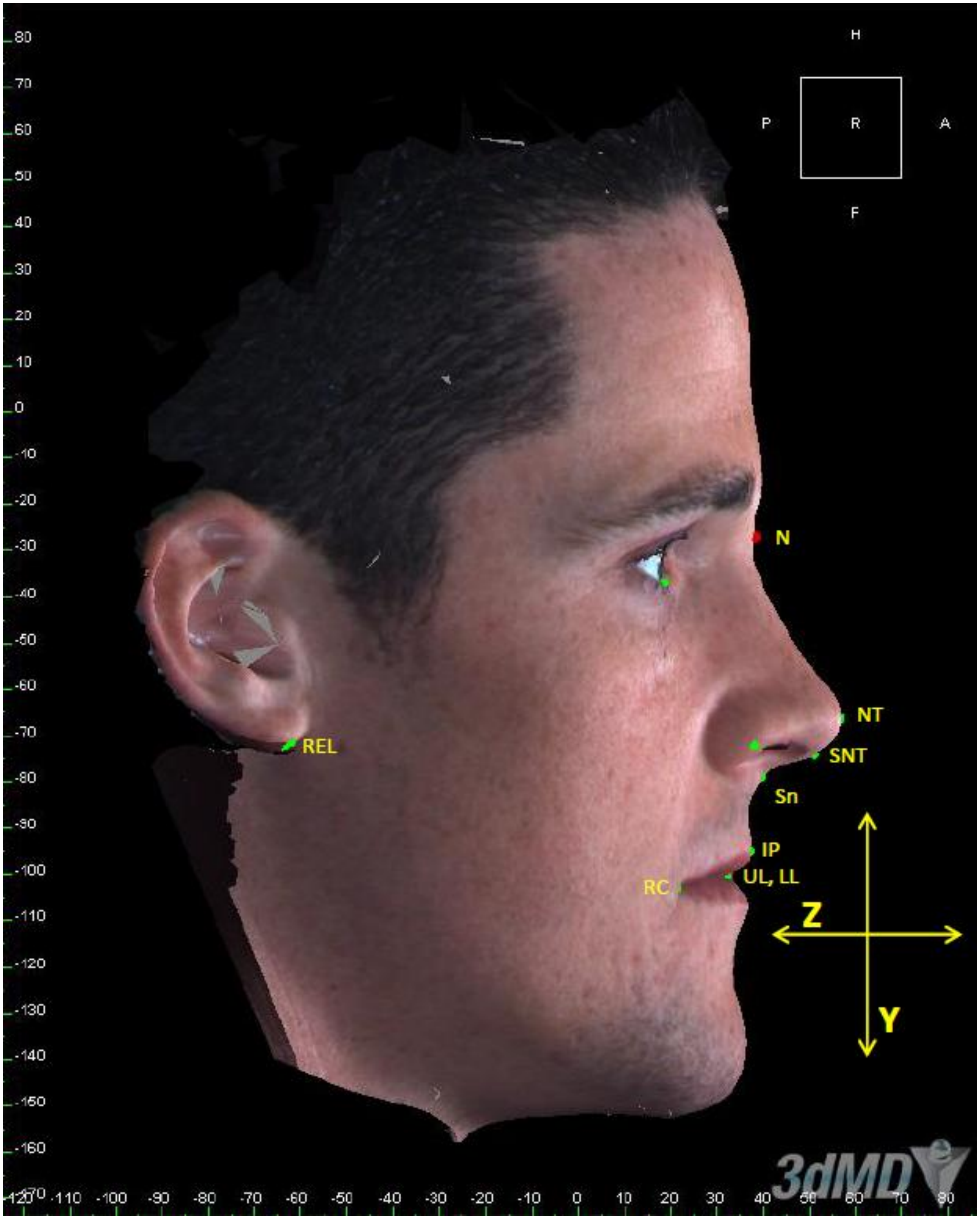


Figure 4: Smiling front

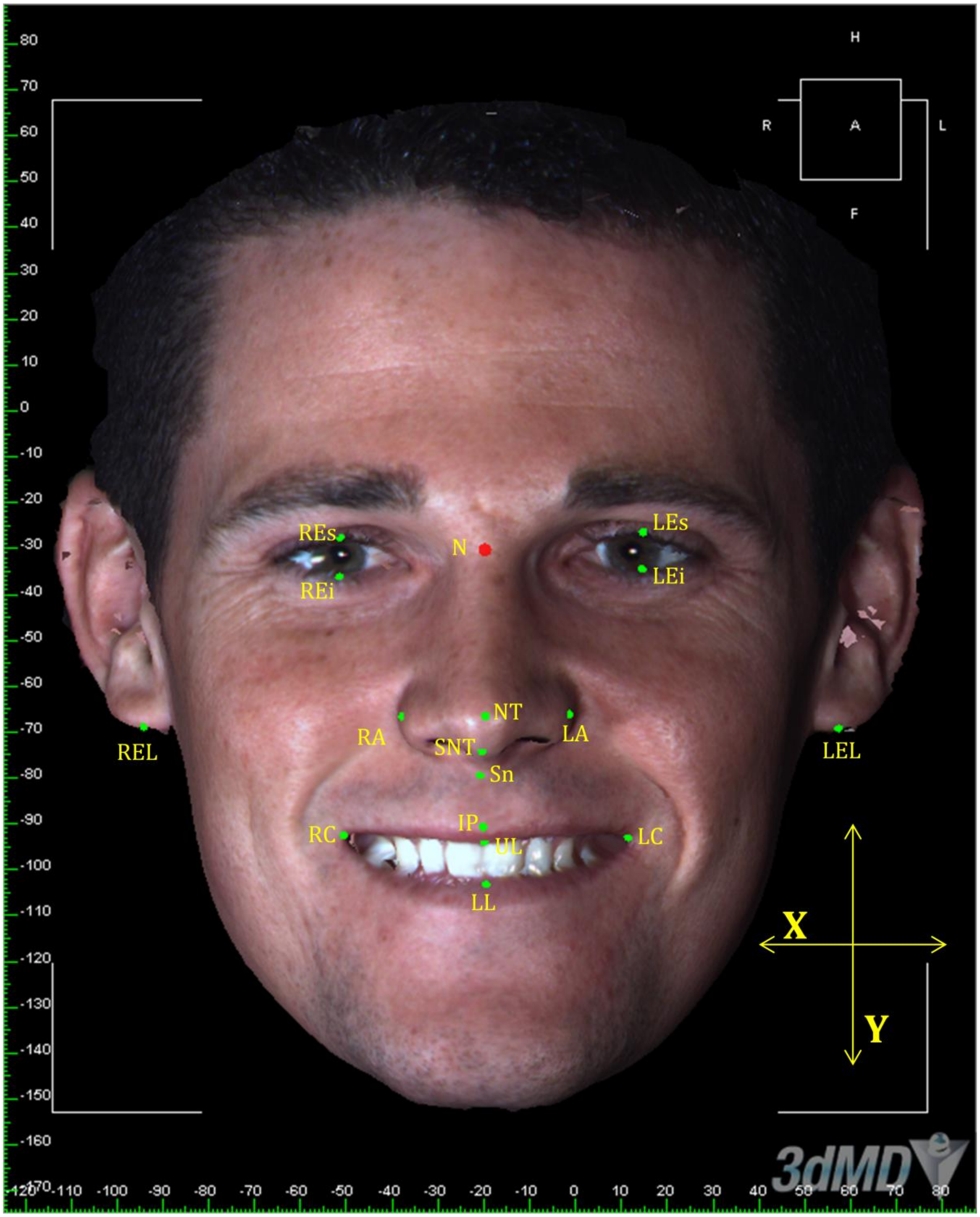
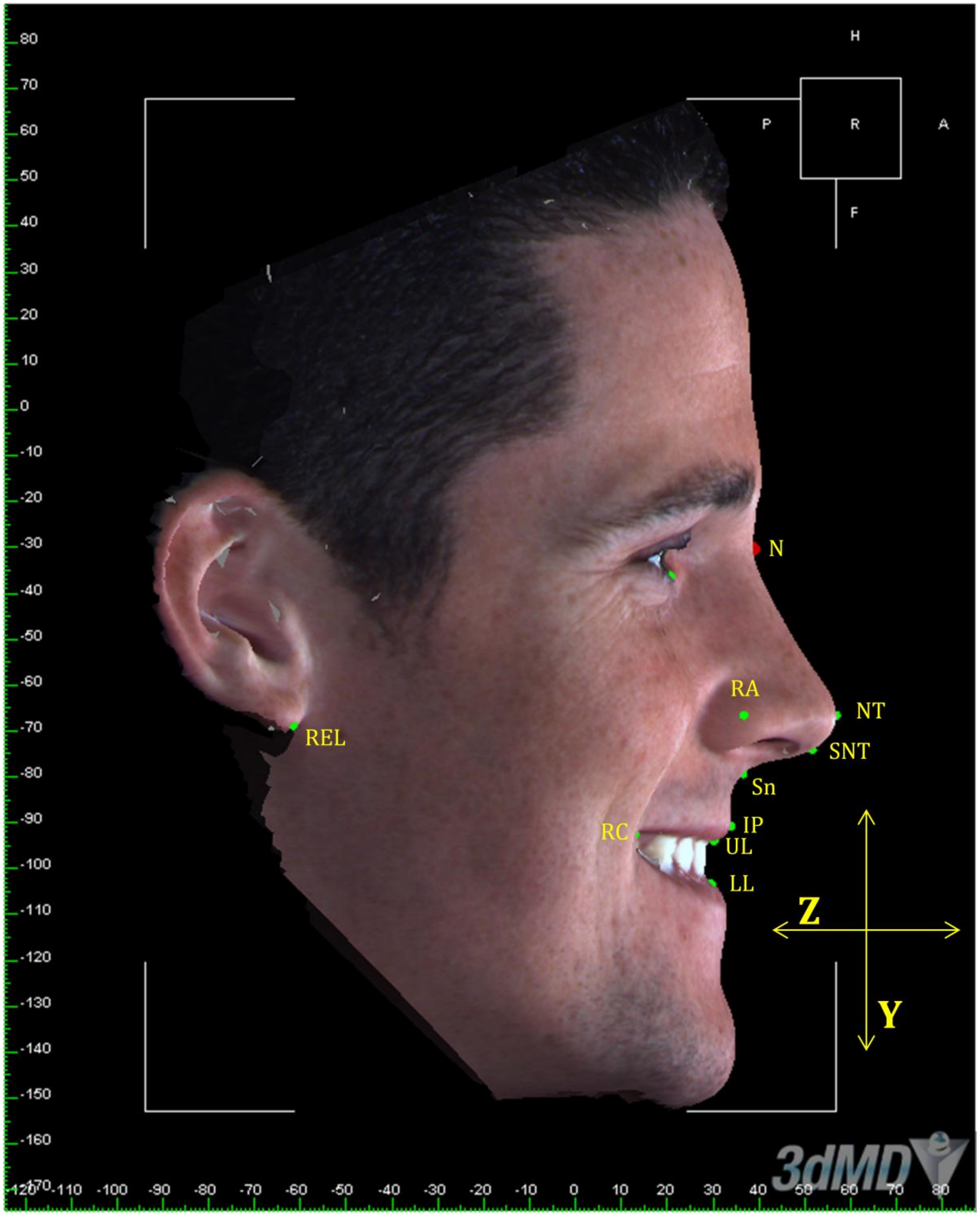


Figure 5: Smiling sagittal



Statistical Analysis

Five of the participants were recalled for a second photographic session. Registration, landmarking, and measurement calculation methods were repeated following the second round of resting and smiling image capture. A repeated-measures mixed-model ANOVA on the log of the absolute differences was used to test for method reliability. A repeated-measures mixed-model ANOVA was also utilized to make comparisons between resting and smiling measurements and between males and females. Significance was established at $P < 0.05$.

Results

Description of the subjects

The participants who met all inclusion criteria included 24 males and 30 females with a mean age of 26.12 and 25.28 years, respectively. 78.57% of the participants were Caucasian, 16.07% were Asian, 3.6% were African American, and 1.8% were Pacific Islander.

Reliability and Accuracy

ANOVA indicated no significant difference between the features that were identified again on the 10 repeated images, 2 from each randomly selected participant ($P > 0.2$). The typical deviation in landmark and interlandmark distance was approximately 1 mm. These results are seen in Table IV.

Following each registration to superimpose resting and smiling images, a root mean square (RMS) value was recorded to document the superimposition accuracy. This number represents the square of the average distances between the two surfaces, so low RMS values represent accurate superimpositions. The average RMS value among all participants was 0.14 ± 0.05, and this value was well below 0.5, the value recommended by the software manufacturer as "acceptable."

Table IV. Estimated Deviations on Repeated Photographs (mm)

Feature	Deviation	95% CI	
Nasion	0.53	0.16	1.76
Nasal Tip	0.18	0.05	0.59
Sub-nasal tip	0.85	0.26	2.83
Subnasale	0.49	0.15	1.62
Inferior Philtrum	1.16	0.35	3.86
Right Commissure	1.45	0.44	4.82
Left Commissure	1.38	0.42	4.59
Upper Lip	1.11	0.33	3.68
Lower Lip	0.83	0.25	2.75
Right Alar Point	1.07	0.32	3.56
Left Alar Point	0.53	0.16	1.75
Right Tragus	0.69	0.21	2.29
Left Tragus	2.99	0.90	9.93
Right Superior Eyelid	1.00	0.30	3.33
Right Inferior Eyelid	1.07	0.32	3.57
Left Superior Eyelid	1.56	0.47	5.18
Left Inferior Eyelid	1.21	0.36	4.01

Changes from Rest to Smile

There were significant changes from rest to smile in ocular display, alar width, interlobular width, intercommissure width, and interlabial height. The results are seen in Table V. Ocular display decreased a significant amount in both males and females. It decreased slightly more in males, but the difference between males and females was not significantly different. Both the alar width of the nose and interlobular width of the ears increased on smile for both sexes. However, neither of these changes were significantly different between males and females. As would be expected, both interlabial gap and intercommissure width increased on smile. Intercommissure width increased significantly more in females than males.

Table VI displays the mean linear displacement of the various landmarks that occurred along the y-z plane after the transition from rest to smile. The linear measurements were also broken down into mean changes along the y and z axes. Nasion moved about 1.3 mm in both males and females. The nasal tip also moved minimally. The points along the base of the nose, sub-nasal tip and subnasale, moved significantly more in males than females. All lip movements including the inferior philtrum, upper and lower lip midline points, and the commissures significantly changed position on smile, and these changes did not differ between males and females. The commissures moved superiorly and in a backward direction. The upper lip also moved upward and back which, along with the inferior movement of the lower lip, contributed to the increase in interlabial gap that occurred. Figures 6, 7, 8, and 9 display mean resting landmarks as open circles and filled circles of each respective color represent smiling position.

Figure 6. Male Mean Changes from Rest (open circles) to Smile (filled circles)

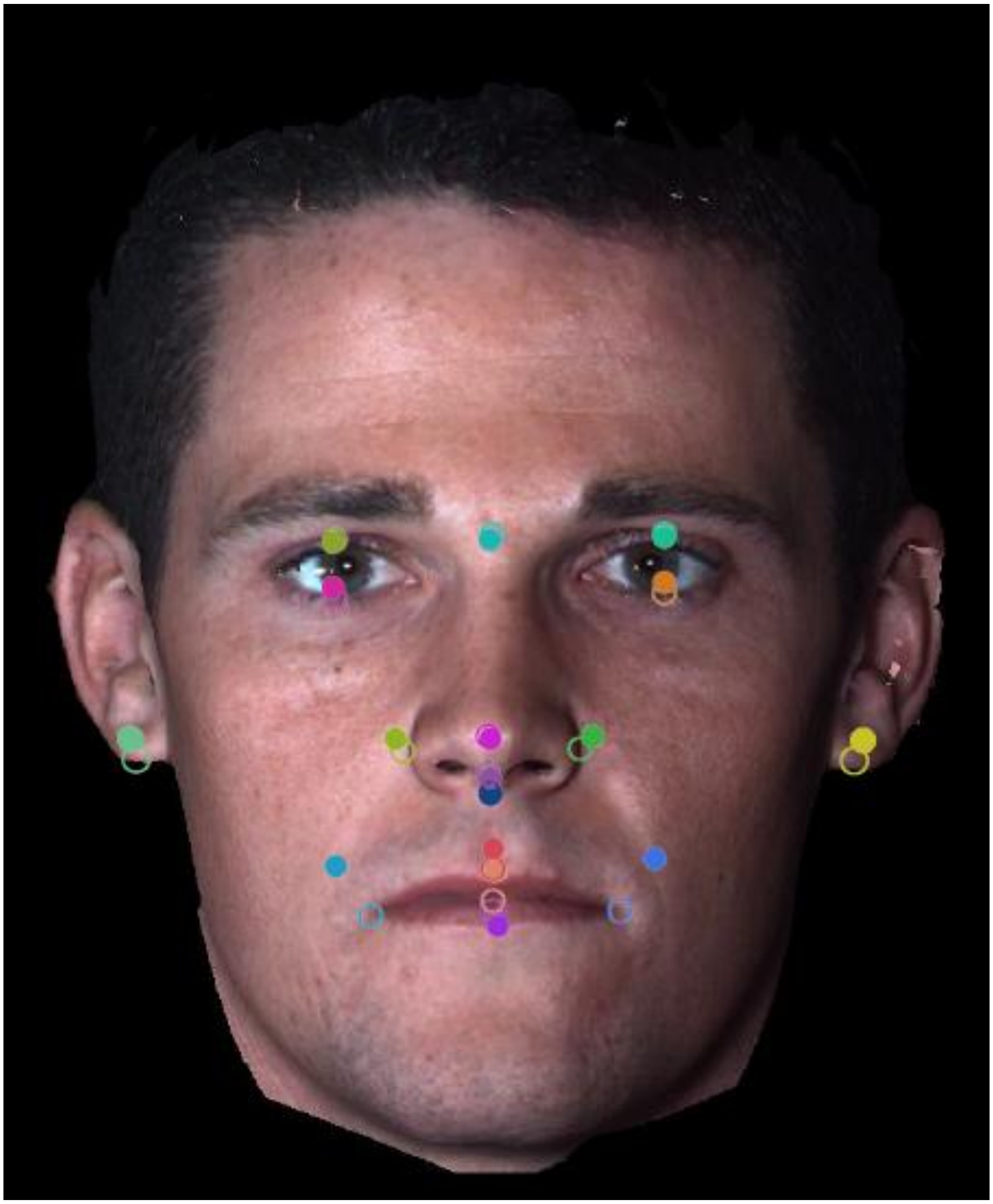


Figure 7. Male Profile Mean Changes from Rest (open circles) to Smile (filled circles)

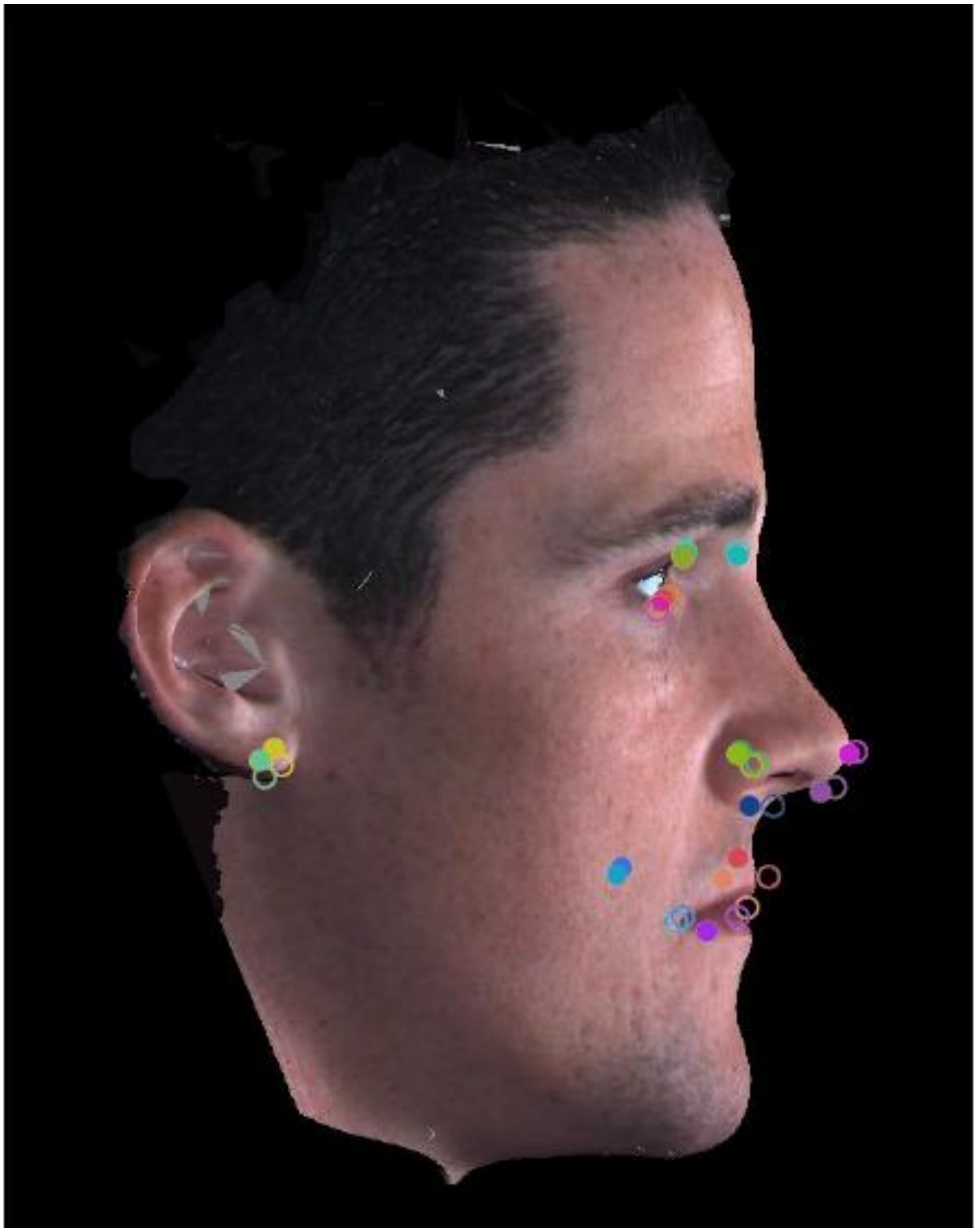


Figure 8. Female Frontal Mean Changes from Rest (open circles) to Smile (filled circles)

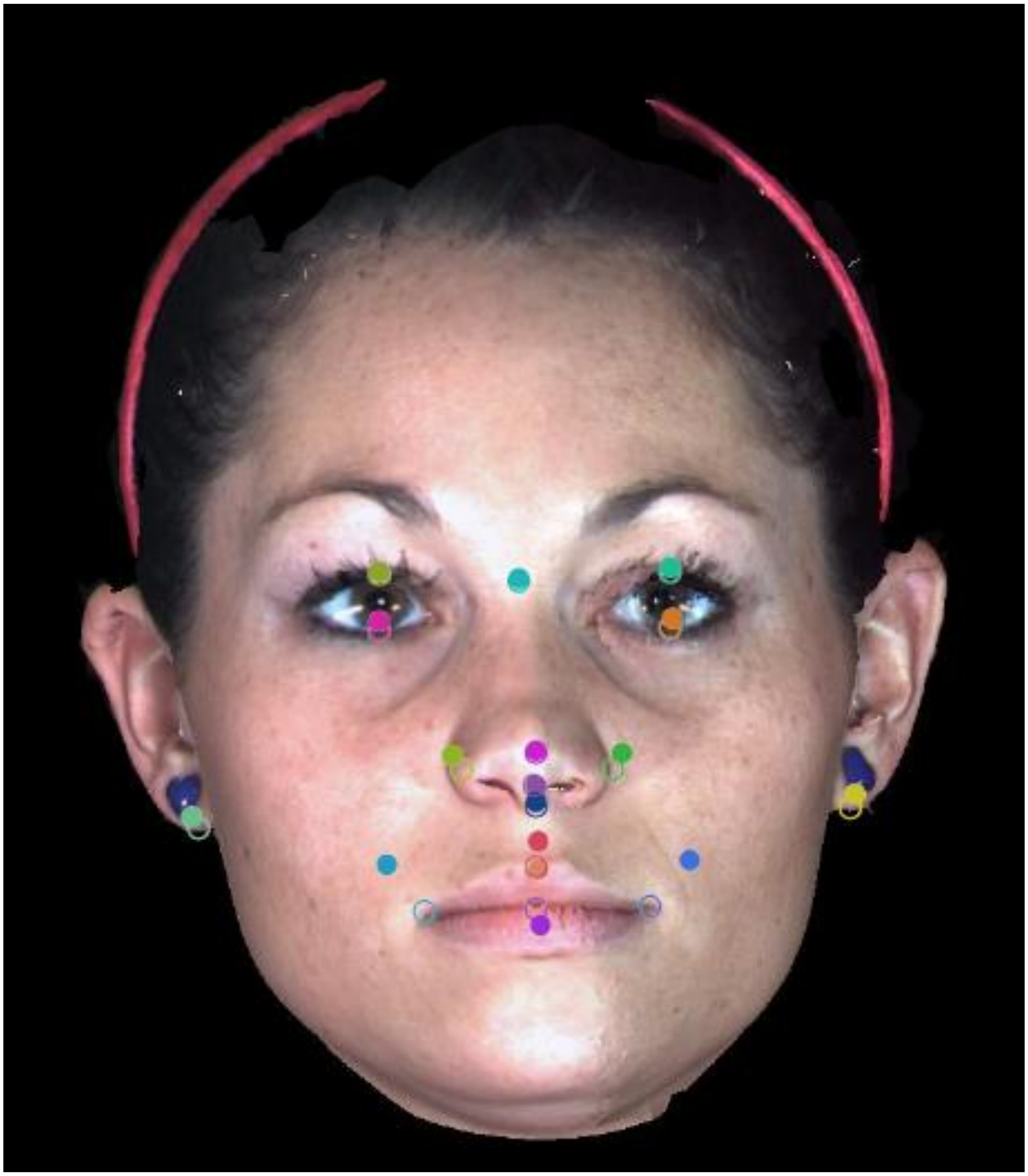


Figure 9: Female Profile Mean Changes from Rest (open circles) to Smile (filled circles)

Table V. Interlandmark distance changes from rest (R) to smile (S) (mean ± SD mm)

	Female			Male					
Measurement	Rest	Smile	P	Rest	Smile	P	Female Δ	Male Δ	P
Ocular Display	11.8 ± 2.8	10.5 ± 1.7	> 0.0001	11.2 ± 1.2	9.1 ± 1.7	> 0.0001	-1.4 ± 2.5	-2.1 ± 1.3	0.1766
Interlobular Width	137.1 ± 5.7	139.6 ± 5.3	> 0.0001	149.1 ± 6.7	151.7 ± 6.8	> 0.0001	2.5 ± 1.8	2.6 ± 1.9	>0.08
Alar Width	32.2 ± 3.13	36.5 ± 3.5	> 0.0001	35.5 ± 3.4	39.3 ± 3.7	> 0.0001	4.3 ± 1.3	3.8 ± 1.7	>0.2
Interlabial Gap	2.8 ± 1.9	12.6 ± 2.3	> 0.0001	2.7 ± 12.6	11.7 ± 2.7	> 0.0001	9.8 ± 2.6	9.0 ± 2.6	>0.3
Intercommissure Width	48.7 ± 3.3	64.8 ± 4.4	> 0.0001	50.0 ± 3.3	64.0 ± 4.1	> 0.0001	16.1 ± 3.7	14.0 ± 3.3	0.029

Table VI. Landmark changes along the y, z axes (mean ± SD mm)

	Female			Male				
Landmark	Linear	ΔY	ΔZ	Linear	ΔY	ΔZ	F-M Linear Difference	P
Nasion	1.30 ± 0.7	0.69	0.29	1.27 ± 0.7	-0.6	0.14	0.03 ± 0.7	0.8824
Nasal Tip	1.45 ± 0.7	0.44	-0.66	1.90 ± 1.2	0.51	1.44	-0.45 ± 1.4	0.0844
Subnasal Tip	1.55 ± 0.84	0.23	-0.89	2.75 ± 1.8	-0.99	-2.41	-1.19 ± 1.36	0.0022
Subnasale	3.15 ± 0.96	1.19	-2.32	4.42 ± 2.4	-0.13	-4.27	-1.27 ± 1.73	0.0098
Inferior Philtrum	7.21 ± 1.5	5.34	-4.64	7.36 ± 1.6	3.84	-6.06	-1.01 ± 0.69	0.7117
Commissures	12.85 ± 2.92	9.91	-11.47	12.47 ± 3.01	10.2	-11.47	0.38 ± 2.96	0.6377
Upper lip	6.94 ± 1.6	6.85	-3.4	6.45 ± 1.98	6.35	-4.49	0.48 ± 1.8	0.3252
Lower lip	3.73 ± 1.8	-3.24	-4.47	3.38 ± 1.8	-2.88	-6.13	0.35 ± 1.79	0.4752

Discussion

As patients continue to present with expectations of ideal smile esthetics, orthodontists must continue to expand their understanding of the function of a smile. Appropriate vertical maxillary incisor and gingival display are important aspects of an esthetic smile, and different treatment options including various orthodontic techniques: Botox, lip repositioning, or even orthognathic surgery are available to meet objectives regarding this smiling characteristic. The selection among these options relies upon analysis of multiple intraoral, extraoral, skeletal, and soft tissue characteristics. Patients will present with varying levels of lip mobility and overall soft tissue changes that occur during the transition from a resting to a smiling position. The results in the current study provide average 3-dimensional facial changes that can be expected in young adults as they transition from rest to a posed smiling position.

Video capture of the smile transition has been previously proposed to ensure that a repeatable smile image is achieved for both clinical treatment planning as well as research purposes.[14] Because the 3dMDface camera system is not designed to capture videos, special care was taken during photographic sessions to maintain method precision. Previous studies have demonstrated that posed smiling images are reproducible and can be generated on command.[16,22] Capturing new images on the randomly recalled participants allowed a reliability analysis of the repeatability of methods as well as the repeatability of the resting and smiling images utilized for comparison. Landmark error was approximately 1 mm on average, results which failed to distinguish significant differences between original landmarks and the recalled group, therefore confirming method reliability and image repeatability.

The results from this study indicate that it is possible to utilize 3-dimensional images to quantify changes that occur when someone transitions from a resting facial position to a smile, and 3-dimensional assessment is important as changes do occur in all spatial planes. The ears moved laterally from rest to smile as was indicated by an increase in interlobular width. Ocular display decreased by about 1.5 mm in females and 2 mm in males, suggesting that there is a consistent amount of squinting that occurs among males and females alike during smile. As is seen in Figure 6 and 8, superior migration of the inferior eyelid is mostly responsible for this decrease. Though increased movement of the lower eyelid may occur when smiling, the upper eyelid maintains increased functionality during protective eye closure (blinking).[23] The nasal region also showed significant changes during smile. A distinct amount of widening during smile was seen in both sexes, and males showed significant changes at the base of the nose. Though these other regions of the face showed significant changes during smile, the most prominent movements were observed in the upper and lower lips.

Basic dimensional changes in the lips included lateral increases in intercommissure width and vertical increases in interlabial gap. Changes in the lips occurred in all 3 dimensions. Though the intercommissure width changes were different between males and females, the linear changes in the y-z plane were not. Both male and female commissures moved superiorly about 10 mm and posteriorly 11.5 mm. The upper lip showed greater mobility than the lower lip, moving about 7 mm in females and 6.5 mm in males in a superior, posterior direction. The lower lip shifted about 3.7 mm in females and 3.4 mm in males in an inferior, posterior direction. The intercommissure width increased more in females than males, and this is consistent with previous reports.[7,24] For example, one study found that in a group of 20-40 year olds, females showed more frequent and more expansive smiles.[24] It has also been shown that females are 2.5 times more likely to have a high smile pattern,[7] but the results from the current study did not show a significant increase in upper lip movement on smile in females as compared to males. Combining females' more expansive soft tissue changes when smiling with the fact that their teeth and arch forms are smaller than males could suggest a predicted increase in buccal corridor space in females, but this correlation has not been established.[25]

Smile features depicted in the current study portray smile mobility for a defined age group between 20-35 years, but smile dynamics would be expected to change over time as these individuals age. A recent study observed the changes in upper lip length, intercommissural width, commissure height, and lip thickness that occur during the transition from rest to smile in multiple age groups. They found that as the age of the groups increased, the observed amount of change in these variables decreased.[26] Suggested causes included decreased resting tonus and elasticity as well as a decrease in activity of facial muscles. A separate study quantified some of these changes, finding that maxillary incisor display on smile decreases 1.5 to 2 mm during the aging process.[27] Future studies utilizing 3-dimensional analysis could examine a cross-sectional sample to allow comparison between different age groups to detect how the aging processes affect the smile in all planes of space.

Conclusions

- Facial soft-tissue changes upon smiling occur in all three dimensions.
- In addition to the lips, the eyes, nose, and ears changed position during the transition from a resting facial position to a posed smile.
- Intercommissure width upon smile increased more in females than males.
- The base of the nose showed more mobility in males than females during the production of a smile.

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Vita

Dr. Clayton McEntire was born October 1, 1984 in Birmingham, Alabama. He graduated as a valedictorian of his class from Oak Mountain High School in 2003. He then attended Auburn University where he played on the men's club soccer team and graduated Summa Cum Laude in 2007 with a degree in Biomedical Sciences. Later that fall he started dental school at the University of Alabama at Birmingham, where he graduated first in his class in 2011. Clay was then granted admission to the Virginia Commonwealth University Department of Orthodontics graduate program. He received his orthodontic certificate in addition to a Master of Science in Dentistry degree in 2013, and will enter into private practice of orthodontics in Tampa, Florida.