The Difference in Facial Movement Between the Medial and the Lateral Midface: A 3D Skin Surface Vector Analysis

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Abstract

Background: Our understanding of the functional anatomy of the face is constantly improving. To date, it is unclear whether the anatomic location of the line of ligaments has any functional importance during normal facial movements such as smiling.

Objectives: It is the objective of the present study to identify differences in facial movements between the medial and lateral midface by means of skin vector displacement analyses derived from 3D imaging and to further ascertain whether the line of ligaments has both a structural and functional significance in these movements.

Methods: The study sample consisted of 21 healthy volunteers (9 females & 12 males) of Caucasian ethnic background with a mean age of 30.6 (8.3) years and a mean BMI of 22.57 (2.5) kg/m^2. 3D images of the volunteers' faces in repose and during smiling (Duchenne type) were taken. 3D imaging-based skin vector displacement analyses were conducted.

Results: The mean horizontal skin displacement was 0.08 (2.0) mm in the medial midface (lateral movement) and was -0.08 (1.96) mm in the lateral midface (medial movement) ($p = 0.711$). The mean vertical skin displacement (cranial movement of skin toward the forehead/temple) was 6.68 (2.4) mm in the medial midface whereas it was 5.20 (2.07) mm in the lateral midface ($p = 0.003$).

Conclusions: The results of this study provide objective evidence for an antagonistic skin movement between the medial and the lateral midface. The functional boundary identified by 3D imaging corresponds to the anatomic location of the line of ligaments.

Our collective appreciation and comprehension of facial biomechanics has improved substantially during the last decades due to a growing understanding of the functional anatomy of the face. Much of this has been driven by the interest in various surgical and minimally invasive facial procedures. [1] Many new concepts that have expanded our knowledge of facial anatomy and biomechanics have been added to the literature recently, of which the layered arrangement of facial soft tissues and the age-related positional changes of the superficial and deep fat compartments seem to have the greatest relevance.[2–5]

Clinical studies have incorporated and applied these novel anatomic concepts and established new treatment strategies to ameliorate the signs of facial aging utilizing minimally invasive procedures. The most influential of these are the *Lateral First* treatment algorithm [6] which utilizes the line of ligaments [5,7] and the *Temporal Lifting* injection technique [8] which utilizes the layered arrangement of fascial planes in the lateral face. [9,10] These studies demonstrated better clinical outcomes with the implementation of these novel anatomic concepts into daily clinical practice.

The separation between the medial and lateral face was previously identified by anatomic dissections and was termed *The Line of Ligaments* [5] due to the contribution of four facial ligaments which had been independently described in the past.[11–21] The biomechanical missing link, however, is whether the line of ligaments is not just a structural boundary, but also a functional boundary separating the movement of facial soft tissues located in the medial and the lateral face. With novel imaging modalities (3D imaging [22–30]) and state-of-the-art analytic methods (skin vector displacement analyses [6,7,28,29]), it can be distinguished if the skin in the medial face moves differently in magnitude and direction when compared to the skin of the lateral face. Also utilizing such technology, it can be shown whether the boundary between these two regions of the midface corresponds to the anatomic location of the line of ligaments. The results of such analyses can further improve our understanding of facial biomechanics and close knowledge gaps between static and dynamic anatomic concepts, the latter of which better represents our daily clinical practice.

It is the objective of the present study to identify differences in facial movements between the medial and lateral midface by means of skin vector displacement analyses derived from 3D imaging and to further ascertain whether the line of ligaments has both a structural and functional significance in these movements.

METHODS

Study Sample

The study was conducted in July 2020 and data was analyzed in August 2020. The volunteers were recruited at the Department for Hand, Plastic and Aesthetic Surgery, Ludwig–Maximilian University Munich, Germany. Inclusion criteria for this study were no previous facial surgeries, no previous facial trauma, no facial soft tissue filler injections and no neuromodulator treatment six months prior to the beginning of this investigation. Each participant provided written informed consent for the use of both their personal data and associated images for educational and scientific purposes. The study was approved by the Institutional Review Board of the Ludwig–Maximilian University Munich (IRB protocol number: 266-13). This study was conducted in accordance with regional laws (Germany) and good clinical practice.

Image Analysis

A 3D image of the volunteers' face in repose was captured at baseline (baseline image). Volunteers were then asked to smile normally, and a follow-up 3D image was captured (follow-up image). The smile included the contraction of both the zygomaticus major and the orbicularis oculi muscles resembling Duchenne-type smiling in all subjects for standardizing purposes. [31]

3D images were captured with a Vectra H2 hand-held camera system (Canfield Scientific Inc., Fairfield, New Jersey, USA) and the generated images were imported in the proprietary Vectra Software Suite and processed for further analysis. The follow-up image (smiling) was compared to its respective baseline image (repose) in each volunteer allowing for in-person comparisons.

The proprietary software algorithm utilizes skin pores, moles, and other prominent 2D skin features as identification markers on the skin surface and compares the position of those features in both the baseline, repose image and in the follow-up, smiling image. The difference in position of those markers is automatically calculated and the positional change is given as skin vector displacement with each vector having a direction and a magnitude of skin movement (values presented in millimetres). The results presented, capture the x- and the y- coordinates in a Cartesian coordinate system but due to the soft algorithm, no z- axis information is provided. This methodology was described previously in detail. [8,28,29,32–34]

Facial Regions of Interest

The regions of interest in the present study were the medial and lateral aspects of the middle face (Figure 1). The middle face is bounded superiorly by a line connecting the lateral canthus and the superior aspect of the tragus, whereas the inferior boundary is formed by a line connecting the corner of the mouth to the inferior aspect of the tragus. The medial midface is separated from the lateral midface by the line of ligaments which is represented on the skin surface by a vertical line connecting the lateral bony orbital rim to the caudal end of the labiomandibular sulcus.[11–21]

The boundaries of the medial midfacial region of interest were: the inferior orbital rim (superior), the lateral side of the nose (medial), the line of ligaments (lateral) and the nasolabial sulcus (inferior). The boundaries of the lateral midfacial region of interest were: the line of ligament ligaments (medial), the tragus (lateral), the zygomatic arch (superior), a connecting line between the oral commissure and the inferior aspect of the tragus (inferior) (Figures 1 and 2).

For the purposes of this study, the medial and lateral midface were compared for their individual skin displacement: horizontal skin displacement indicates movement of skin laterally towards the ear and vertical skin displacement indicates skin movement cranially towards the forehead/temple (Figure 2).

Statistical Analyses

Data analysis revealed normally distributed values for horizontal and for vertical skin displacement with Shapiro Wilk testing providing values of $p = 0.507$ and $p = 0.274$, respectively. Due to normal distribution of data, independent Student's t-test was conducted. Generalized linear models were additionally executed to identify potential influences of age, gender or BMI. All analyses were performed using SPSS Statistics 23 (IBM, Armonk, NY, USA) and differences were considered statistically significant at a probability level of ≤ 0.05 to guide conclusions.

RESULTS

General Findings

The study sample consisted of 21 healthy Caucasian volunteers (9 females & 12 males) with a mean age of 30.6 (8.3) years [range: 20 – 54] and a mean body mass index of 22.57 (2.5) kg/m^2 [range: 18.4 – 26.9].

Medial vs. Lateral Midface Comparisons: Horizontal Skin Displacement

The mean horizontal skin displacement (lateral movement of skin toward the ear) was 0.08 (2.0) mm in the medial midface and was -0.08 (1.96) mm in the lateral midface with $p = 0.711$. The opposite direction of vectors indicated by the negative values in the lateral midface indicates that the skin in the lateral midface moves away from the ear and toward the medial midface. In the medial midface, however, the skin moves toward the ear; this is represented by the positive values in horizontal skin displacement.

Upon image analysis, it was revealed that the two antagonistic movements collide at a vertical line located at the lateral orbital rim; this corresponds to the location of the line of ligaments (Figures 3-8).

Medial vs. Lateral Midface Comparisons: Vertical Skin Displacement

The mean vertical skin displacement (cranial movement of skin toward the forehead/temple) was 6.68 (2.4) mm in the medial midface, whereas it was 5.20 (2.07) mm in the lateral midface ($p = 0.003$) (Figures 3-7 and 9).

Male vs. Female Comparisons

Males had greater vertical skin displacement than females in the medial midface – 7.95 (2.29) mm vs. 4.99 (1.26) mm (male vs. female, with $p < 0.001$) – and in the lateral midface – 6.37 (1.75) mm vs. 3.64 (1.31) mm (male vs. female, with $p < 0.001$). No such differences between genders were observed for values of horizontal skin displacement in either the medial or the lateral midface.

Multivariate Analyses

Generalized linear models with adjustment for age and BMI revealed that age did not have a statistically significant influence on the magnitude of horizontal or vertical skin displacement in either males or females. However, higher values of BMI did have a statistically significant influence on vertical skin displacement with 1 unit increase in BMI associated with a greater vertical skin displacement by 0.50 mm in males ($p = 0.021$). No such influence of BMI was observed in females ($p = 0.894$) or in measures of horizontal skin displacement in either gender.

DISCUSSION

The objective of this study was to investigate the movement of skin in the medial and lateral midface during Duchenne type smiling utilizing objective analyses provided by 3D imaging. The study was carried out in 21 Caucasian volunteers analysing a total of 42 hemi-faces. It was observed that the skin of the medial midface moves towards the ear, whereas the skin of the lateral midface moves toward the nose during Duchenne type smiling; this would seem to indicate antagonistic movement patterns. Interestingly, the area where this divergent skin movement pattern converged was located in a vertical line connecting the lateral orbital rim to the inferior end of the labiomandibular sulcus; this is identical to the previously described anatomic location of the line of ligaments.

The ligaments contributing to the formation of the line of ligaments are (from cranial to caudal) the temporal ligamentous adhesion, the lateral orbital thickening, the zygomatic ligament and the mandibular ligament. These four ligaments originate from the periosteum of their respective bones and fan out into multiple connective tissue fibres adhering to the deep dermis. Medial to the line of ligaments, the muscles of facial expression can be identified, whereas no muscles of facial expression (anatomic variations excluded) are found lateral to this vertical line. Lateral to this line, the muscles of mastication can be identified – with the masseter and temporalis muscles being the most prominent in terms of their contribution to shaping the face. [35]

The volunteers included in this study were asked to smile (the influencing variable of this analysis); this resulted in the contraction of the medially located zygomaticus major and minor muscles and of the orbicularis oculi muscle. The surface effect of these combined muscular actions was captured in 3D imaging and decoded into a 2D Cartesian coordinate system with horizontal and vertical movement components. The surface effect of the vertical skin movement component had a statistically significant increase in the medial midface when compared to the lateral midface – 6.68 mm vs. 5.20 mm (medial vs. lateral midface, $p = 0.003$). This effect can be attributed to the location of the muscles of facial expression which are found medially but not laterally. A previous anatomic study identified a new anatomic structure located in the medial midface which the authors termed the transverse facial septum. [23] This septum connects the underside of the zygomaticus major muscle to the maxilla and forms the inferior boundary of the deep midfacial fat compartments. [3,23] The contraction of the zygomaticus major muscle, as observed during smiling, was reported to elevate the midfacial soft tissues. Moreover, this phenomenon was observed in the current study in the medial midface and was supported by the magnitude of vertically oriented skin displacement. Interestingly, we also found a statistically significant increase in the magnitude of vertical skin displacement in volunteers with higher BMI values ($p = 0.021$). This is plausible because at higher values of BMI, the thickness of facial fat is increased; this increase in facial fat overlies the muscular plane and results in a greater magnitude of cranial skin displacement during smiling. [36]

Horizontal skin movement displayed an antagonistic movement pattern: the skin in the medial midface moving laterally (0.08 mm) and the skin in the lateral midface moving medially (-0.08 mm). The boundary on the skin surface between these two opposing movements was located in a vertical line connecting the lateral orbital rim to the inferior end of the labiomandibular sulcus. This surface location corresponds with the position of the previously described line of ligaments – composed of four individual retaining ligaments of the face.[11–21] From a biomechanical point of view, it still needs to be determined whether the line of ligaments forms this functional boundary by itself – representing a *ligamentous wall* – or whether the *location* of the ligaments is, by coincidence, where the contractile force of the muscles of facial expression ends.

Support for the *ligamentous wall hypothesis* comes from a previous study which described conclusively, by using computed tomographic imaging followed by anatomic dissections, the boundaries of the superficial fat compartments. The lateral boundary of the superficial medial cheek fat compartment and the medial boundary of the superficial middle cheek fat compartment correspond to the location of the line of ligaments. [2] This structural demarcation could be formed by the cutaneous insertion of the retaining ligaments and could also form a functional boundary which limits the transmission of medial skin displacement lateral to this line.

Support for the *location hypothesis* comes from detailed anatomic descriptions of the zygomatic ligament. Previous studies have described the location of the strongest facial ligament to be in close proximity to the bony insertion of the zygomaticus major and minor muscles. [20] The contractile capacity of the zygomatic muscles ends at their bony origin and would explain why the medial movement of the skin surface is not transmitted further laterally. The same location in which the zygomatic ligament is found could be pure coincidence and would imply that the ligament itself plays no role in limiting the medial movement of facial soft tissues.

It is important to note that fascial layers of the face are continuous from medial to lateral and vice versa. This layered continuation most likely explains the medial movement of the lateral midfacial soft tissues by the magnitude of 0.08 mm and would explain the cranial movement by the magnitude of 5.20 mm. The lateral soft tissue would follow the cranial movement of the medial soft tissues which is effected by the location of the (medially located) muscles of facial expression.

The sample size of 42 investigated hemifaces could be regarded as a limitation of the study. However, the present study provided an explanatory model for a well-established clinical observation by combining anatomic knowledge and 3D skin surface vector analyses. It is questionable whether a larger sample size would have altered the findings presented herein.

The results presented herein can support and guide surgical and non-surgical facial interventions and potentially explain clinical observations. Based on the results of this study it could be explained why in some patients a distinct medial midfacial hypomimia can be observed after surgical rhytidectomy. During various face-lifting procedures, the medial midfacial soft tissues are tensed and re-positioned into a more lateral position. Therefore, it is plausible that the range of movement of the medial midfacial soft tissues (medial to lateral movement) is reduced due to the re-draping and repositioning of the surgically targeted fascial layers; this is comparable to an over-expanded rubber band which is reduced in its capability to regain its original length. This causes most likely the observed post-surgical hypomimia of the medial midface in some clinical cases.

Deep-plane face-lifting procedures detach the facial soft tissues and reposition them more laterally on a deep fascial level which also alters the location of the line of ligaments. The line of ligaments is a natural boundary between the medial and the lateral midface, which is now re-located toward a more lateral position. This could result in a lateral re-positioning of the medial midfacial soft tissues which could accentuate the reduced range of movement of the medial midfacial soft tissues. Lateral relocation of the line of ligaments combined with a reduced range of motion of the medial midface could be perceived as a less natural surgical outcome and should be considered based on the anatomic results presented herein.

Targeting lateral canthal lines with neuromodulators can influence the balance between lateral and medial movement of the medial vs. the lateral midface, respectively. The muscle majorly responsible for the medial movement of the lateral midface is the lateral aspect of the orbicularis oculi whereas in the medial midface the lateral movement is in addition to the orbicularis oculi supported by the zygomaticus major. Reducing the contractility of the orbicularis oculi muscle can influence the natural amplitude of lateral movement of the medial midface and of the medial movement of the lateral face. This can result in an unfavourable change in the smile of treated patients.

CONCLUSION

The results of this study provide objective evidence that, upon Duchenne type smiling, compared to repose, the skin in the medial midface moves cranially and laterally whereas the skin in the lateral face and moves medially and to a lesser extent also cranially. The boundary between the divergent horizontal movements corresponds to the anatomic location of the line of ligaments. It remains to be further investigated whether these four facial ligaments actively or passively contribute to this functional/biomechanical boundary.

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Figure Legend

Figure 1. Regions of interest exemplified on a female 23-year-old study participant. The middle face is outlined by the black dotted line whereas the line of ligaments is indicated by the white dotted line. The latter separates the middle face into a medial midface (MM) and into a lateral midface (LM). Along the line of ligaments four facial ligaments can be identified: temporal ligamentous adhesion (red dot), lateral orbital thickening (blue dot), zygomatic ligament (yellow dot) and mandibular ligament (green dot).

Figure 2. Screen capture from the 3D image analysis of a male 32-year-old study participant exemplifying the evaluated regions of interest: Medial midface (MM) and lateral midface (LM).

Figure 3. Analytic sequence of images of a male 32-year-old study participant: repose, smiling and with skin vector analyses superimposed. The projected line of ligaments (white dotted line) corresponds to the separation between the medial and the lateral midface.

Figure 4. Analytic sequence of images of a female 35-year-old study participant: repose, smiling and with skin vector analyses superimposed. The projected line of ligaments (white dotted line) corresponds to the separation between the medial and the lateral midface.

Figure 5. Analytic sequence of images of a female 29-year-old study participant: repose, smiling and with skin vector analyses superimposed. The projected line of ligaments (white dotted line) corresponds to the separation between the medial and the lateral midface.

Figure 6. Analytic sequence of images of a male 62-year-old study participant: repose, smiling and with skin vector analyses superimposed. The projected line of ligaments (white dotted line) corresponds to the separation between the medial and the lateral midface.

Figure 7. Analytic sequence of images of a female 27-year-old study participant: repose, smiling and with skin vector analyses superimposed. The projected line of ligaments (white dotted line) corresponds to the separation between the medial and the lateral midface.

Figure 8. Box plot showing the horizontal displacement in millimeters for the medial and the lateral midfacial movement. Error bars indicate +/- one standard deviation.

Figure 9. Box plot showing the vertical displacement in millimeters for the medial and the lateral midfacial movement. Error bars indicate +/- one standard deviation.

Figure 1

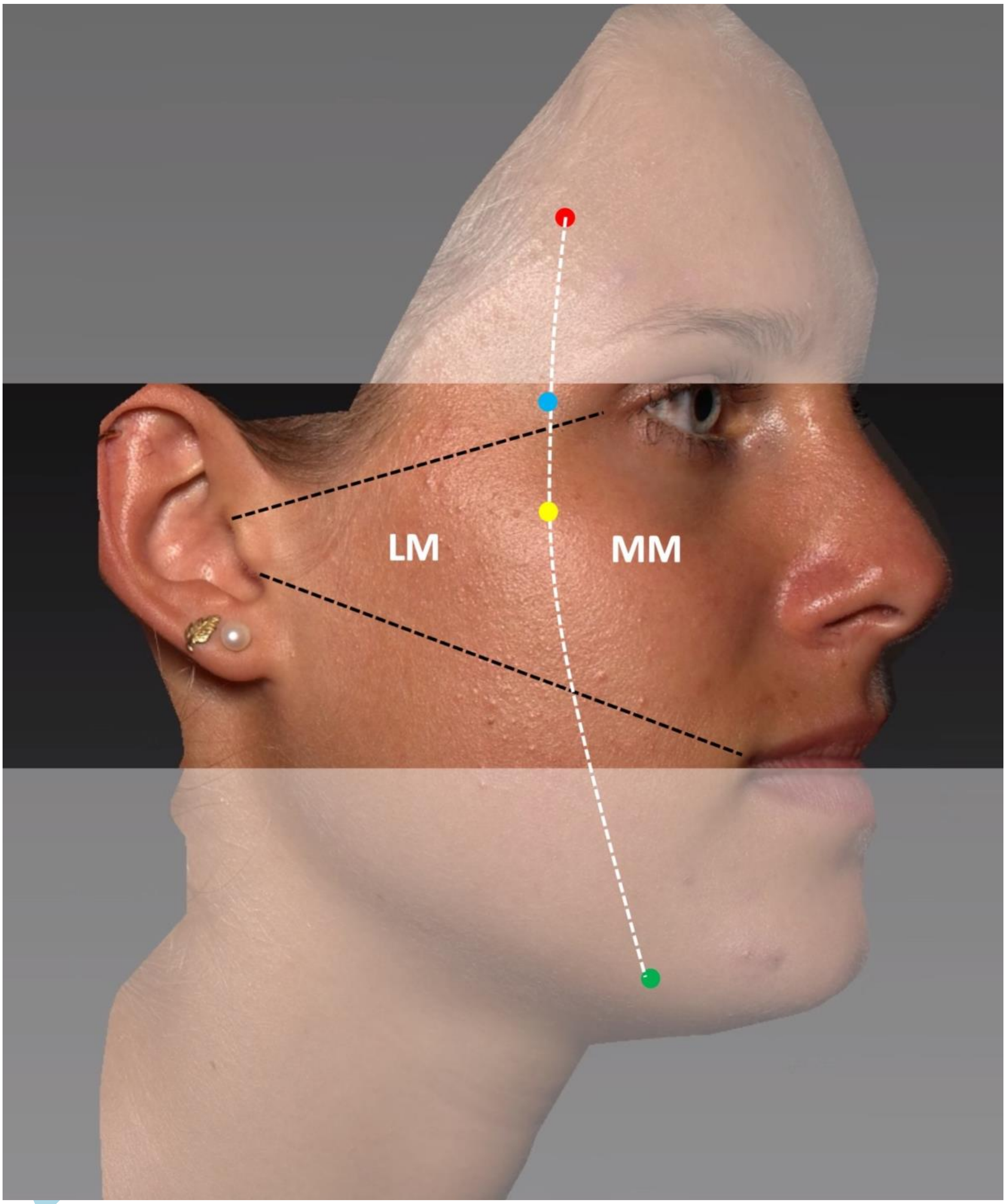
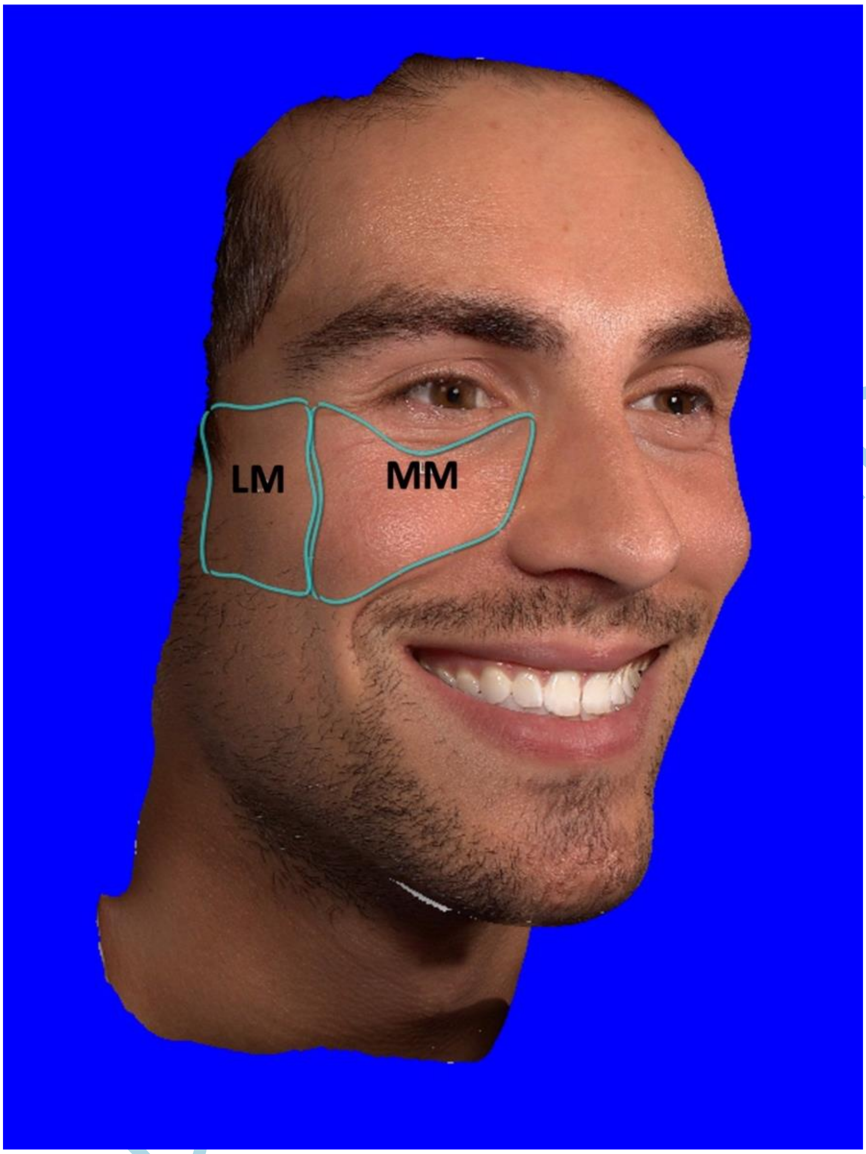


Figure 2



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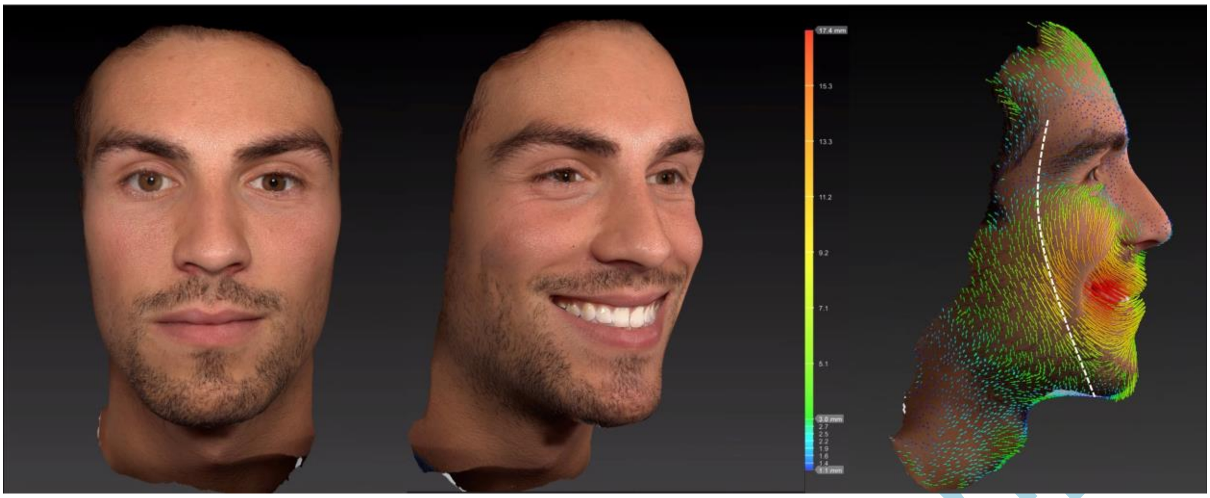

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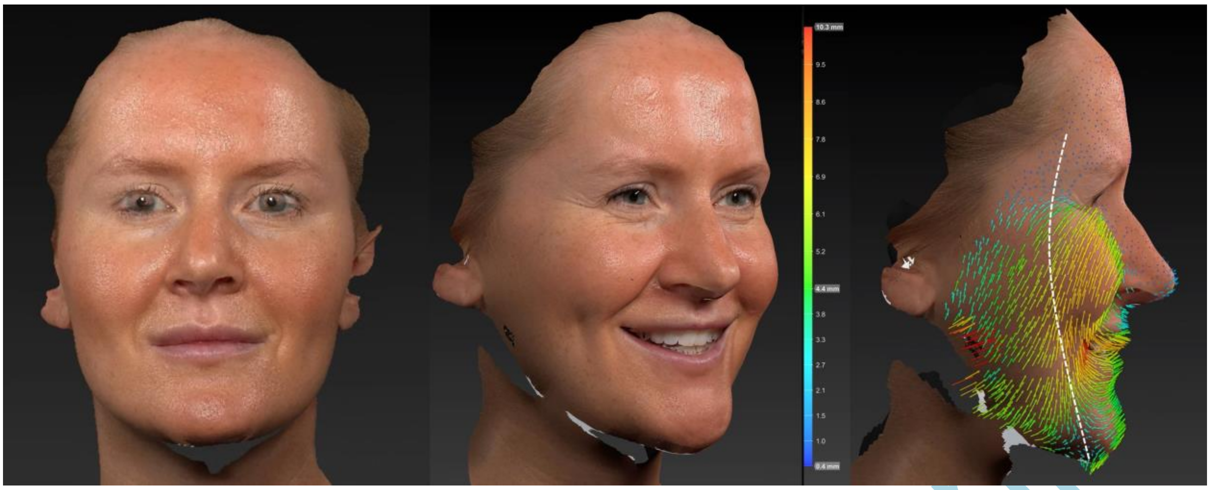


Figure 5

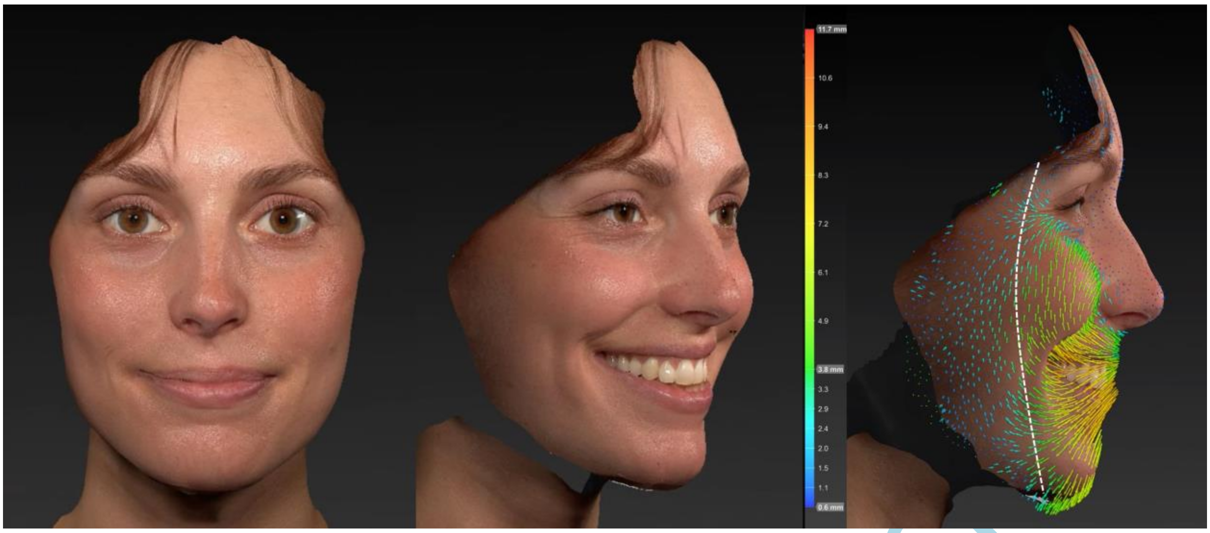


Figure 6

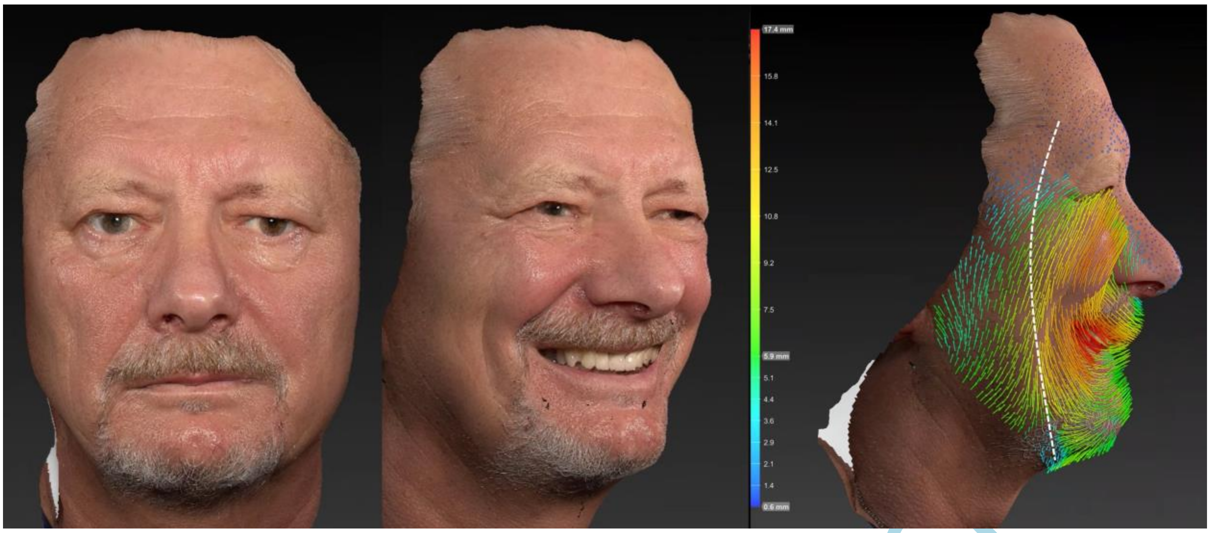
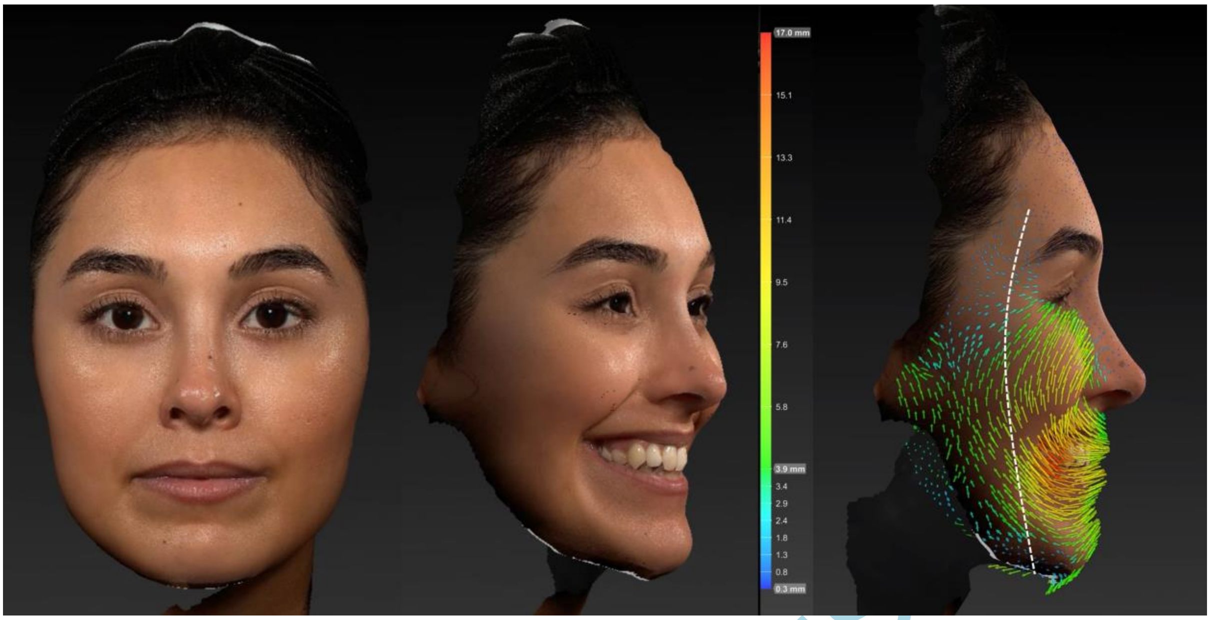


Figure 7



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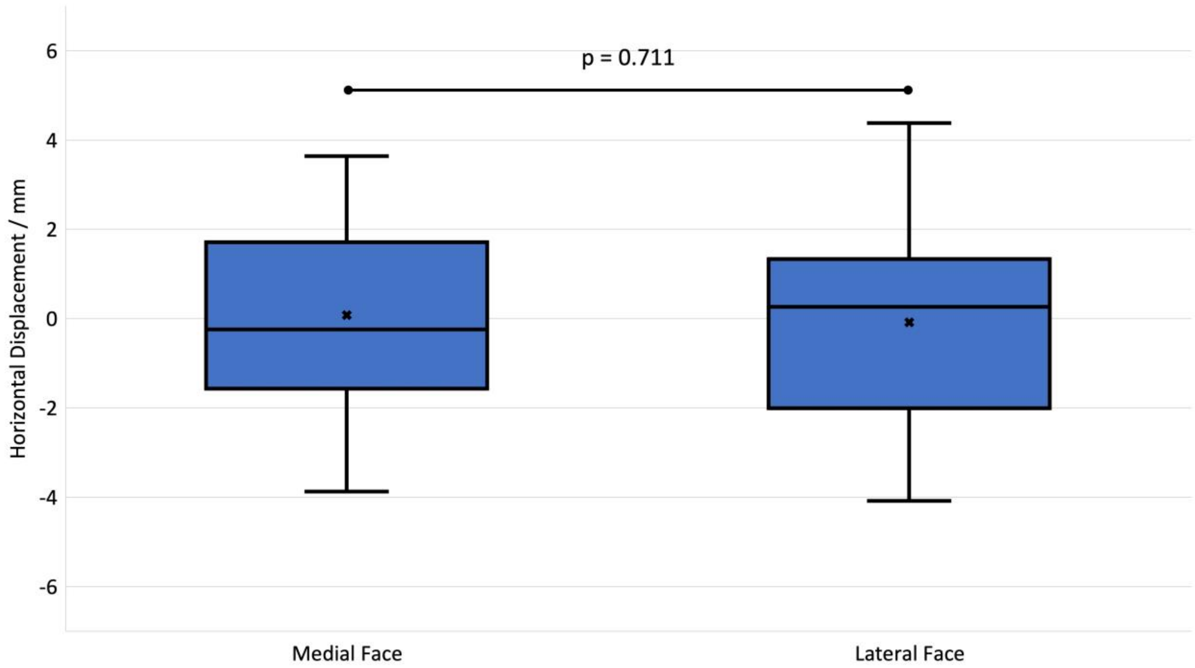
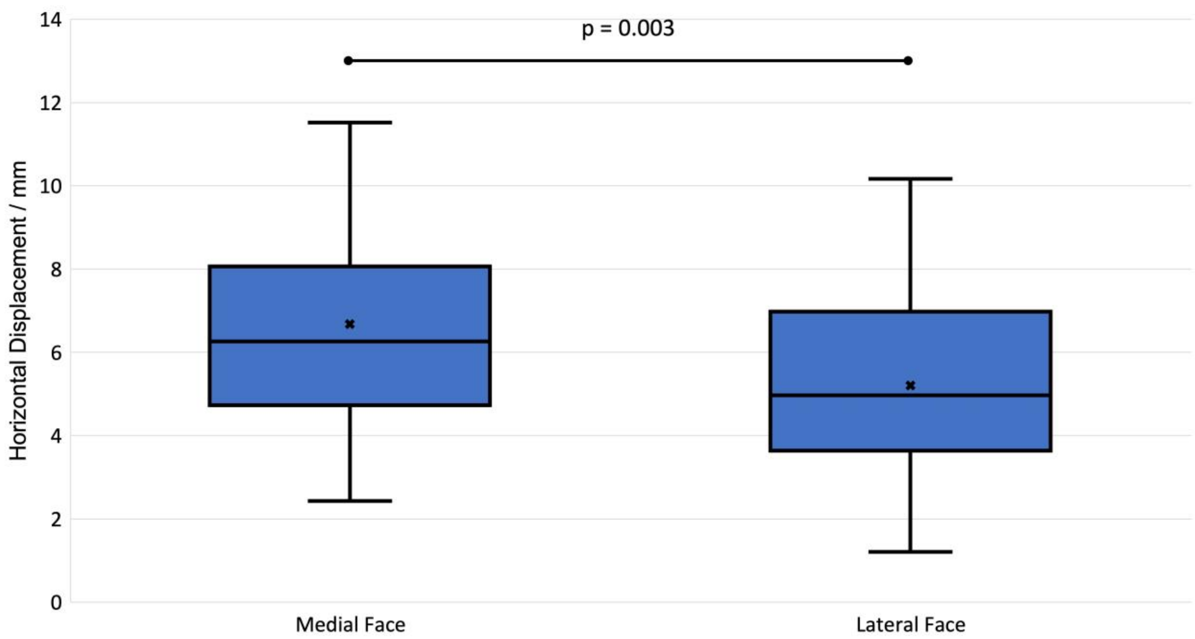


p = 0.711
6
4
2
0
-2
-4
-6
Horizontal Displacement / mm
Medial Face
Lateral Face

Figure 9



p = 0.003
14
12
10
8
6
4
2
0
Horizontal Displacement / mm
Medial Face
Lateral Face