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ORIGINAL INVESTIGATION

Sex Differences in Adult Facial Three-Dimensional Morphology: Application to Gender-Affirming Facial Surgery

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Abstract

Background: Gender-affirming facial surgery (GFS) is pursued by transgender individuals who desire facial features that better reflect their gender identity. Currently, there are a few objective guidelines to justify and facilitate effective surgical decision making.

Objective: To quantify the effect of sex on adult facial size and shape through an analysis of three-dimensional (3D) facial surface images.

Materials and Methods: Facial measurements were obtained by registering an atlas facial surface to 3D surface scans of 545 males and 1028 females older than 20 years of age. The differences between male and female faces were analyzed and visualized for a set of predefined surgically relevant facial regions.

Results: On average, male faces are 7.3% larger than female faces (Cohen's $D = 2.17$). Sex is associated with significant facial shape differences ($p < 0.0001$) in the entire face as well as in each sub-region considered in this study. The facial regions in which sex has the largest effect on shape are the brow, jaw, nose, and cheek.

Conclusions: These findings provide biologic data-driven anatomic guidance and justification for GFS, particularly forehead contouring cranioplasty, mandible and chin alterations, rhinoplasty, and cheek modifications.

Introduction

Facial appearance serves a major role in communication and social interaction. This is evidenced by the existence of an area in the human brain dedicated to the identification of sex, identity, age, and race at a single glance.[1] This fact poses a unique challenge to the transgender population, which was recently estimated to be roughly 1 million people in the United States.[2] Facial surgery enables structural changes to the face, which can help a patient to fully assume a facial appearance that is concordant with their gender identity, thereby reducing misgendering and gender dysphoria

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KEY POINTS

Question: How are the male and female face different in shape and size?

Findings: On average, female faces are smaller, have larger cheeks, and have smaller and less prominent brows, noses, and chins compared with male faces.

Meaning: Alterations of the mandible, brow, lip, nose, and cheeks are important in gender-affirming surgery of the face.

while improving self-perception,[2] and will likely be increasingly performed with increasing insurance coverage.[3,4]

The term ''gender identity'' denotes an individual's deep-seated sense of one's gender. Gender is distinct from sex and refers to behavioral, psychological, or sociocultural traits typically associated with sex. A cisgender individual has a gender identity that matches their sex, whereas a transgender individual's gender identity does not match their sex. A gender non-confirming state may lead to psychological, social, and clinical distress, known as gender dysphoria.[5] For some transgender and nonbinary individuals, the discordance between physical appearance and deep-seated identity that they or others perceive provides a strong motivation to pursue facial and body surgical modifications.

Gender-associated facial surgery has traditionally been referred to as facial feminization surgery (FFS).[6,7] The more inclusive term gender-affirming facial surgery (GFS) captures the whole spectrum of surgery from facial masculinization surgery (FMS) to FFS. FFS is more commonly performed than FMS due to the powerful effects of testosterone supplementation to masculinize the face, and FFS can include a combination of rhinoplasty, frontal bone cranioplasty, hairline alteration, brow lift, mandibular reduction, cheek volume enhancement, face/neck lift, cervicofacial liposuction, vertical lip lift, lip augmentation, and thyroid cartilage chondrolaryngoplasty.[8–10]

The procedures are individualized and depend on a balance between the patient's existing facial features and related dysphoria. Surgeons create plans for GFS based on their previous experience, patients' wishes, and personal and simplified definitions of facial femininity and masculinity. Although there are general gender-related facial alteration guidelines,[11] there are currently no guiding measurements or objective criteria for GFS, and a few evidence-based criteria with which to support GFS or assess its outcomes.

This study aims at providing surgeons, patients, and payors with a surgically oriented analysis of three-dimensional (3D) facial size and shape that quantifies and visualizes facial sex differences. It provides essential, baseline, biologic, and data-driven guidance and justification for a variety of GFS procedures.

Materials and Methods

Data description

The 1573 3D facial scans from healthy subjects used in this study are a subset of the 3D FaceBase dataset,[12] a U.S.-based repository collected between 2009 and 2014 that contains 3D facial surface scans and demographic descriptors. The scans were acquired by using a 3DMD facial imaging system (www.3dmd.com, Atlanta, GA) and are available through a controlled-access repository managed by the FaceBase Consortium. (www.facebase.org).

Each scan is a 3D surface mesh comprising 3D vertices that are connected by triangles. Triangular meshes are commonly used to digitally represent surface data. Although the exact number of vertices (x, y, z Cartesian coordinates) per face can differ slightly in the raw data, each mesh is reduced to 27,903 vertices during the data registration process so that the representation of faces is consistent across the sample.

The subset of participants included in this study comprised all those 20 years of age or older at the time of imaging, had no known congenital facial abnormalities or history of facial trauma or facial reconstruction, and identified their sex as either female or male. Participants' self-identified sex was also confirmed by genetic analysis of saliva samples. Racial and ethnic variation is limited within the dataset; only participants of European-Caucasian ancestry were included. Each facial scan was landmarked by trained human observers with 24 landmarks defined in Weinberg et al.[12]

This study was conducted in accordance with the Declaration of Helsinki. Ethics approval was granted by the Conjoint Health Research Ethics Board (CHREB# REB14-0340_REN4) at the University of Calgary and by the UCSF Institutional Review Board (IRB# 18-24733).

Shape and size measurement

Analyzing 3D facial meshes and other kinds of coordinate data requires quantitative methods beyond simple linear distance measurements, angles, and ratios that encompass traditional biometry. Some of the differences relate to the idiosyncrasies of coordinate data collection. For example, differences in scanned subject location and orientation can potentially alter the 3D x, y, and z distances from an origin along the Cartesian axis, engendering errors in measurements that lead to uninterpretable differences in facial form.

In geometric morphometrics (GM), these nuisance scanning differences are removed by *translating* observations so that the average position of each subject's coordinates is located at a common origin, and *rotating* subjects about that origin so that the differences between them are minimized. After translation and rotation, each subject configuration can be *scaled* to remove differences in centroid size between subjects to analyze shape differences separately from size differences. Centroid size, the most common measure of the size of a landmark configuration in GM, is the square root of the sum of each landmark's squared distance from the centroid where the centroid is the mean landmark position.

After translation, rotation, and scaling, all remaining differences between homologous landmark configurations are considered differences in *shape*, that is, differences in the relative positions of landmarks within the configurations. Moreover, the data can now be subjected to common statistical analyses such as regression and classification. Configurations of identical shape but with different centroid sizes differ in *size* only.

The combined difference in size and shape is referred to as difference in *form*. In GM, the decomposition of form into size and shape components provides an intuitive vocabulary for describing how observations differ. For example, the differences between a baseball and softball can be almost perfectly described by differences in size alone. Similarly, a volleyball and football are virtually identical in size and can be almost perfectly described by their shape differences. A football and baseball differ in both size and shape, the two components of form.

To prepare the subject faces for analysis, a reference facial surface mesh was registered to each scan by using the non-rigid iterative closest point algorithm guided by 24 manually identified landmarks.[13] The registration process produces a one-to-one point correspondence between the 27,903 vertices of the reference surface mesh and anatomically homologous points on each of the subject scans. After this initial registration, each subject mesh was translated and aligned to the reference mesh by rotation about the origin. Thereafter, by comparing the relative locations of homologous points, measures of facial shape and size were calculated. For analyses of facial shape only, size information was removed by scaling subject meshes to a uniform centroid size.[14]

To analyze the effects of sex on size and shape in different facial sub-regions of interest, a variety of regions were first specified based on the potential for surgical application and relevance to surgical decision making and planning. The regions include both large area sections of the face and axial or sagittal curves (Fig. 1). Using the point correspondences produced by the non-rigid registration process, each region was mapped to each individual subject face. After extracting subregions, the same process of measuring size and shape described earlier was then applied to each region. In addition to dense surface-based measurements of form, size, and shape, simple linear distance measurements between pairs of landmarks were measured for each subject (Fig. 1).

Statistical analysis

We quantified the magnitude of sex effects on craniofacial morphology by using standardized effect size statistics (Cohen's D, R^2). Cohen's D measures the average difference between two classes of subjects (e.g., male and female) relative to how much individuals within a class typically differ from each other with respect to a univariate measurement (e.g., size). R^2 is a multivariate effect size statistic, which measures the fraction of total variation that can be accounted for by an external variable (e.g., sex). p-Values for the univariate size and distance analyses were calculated by using Welch's t-test. p-Values for multivariate shape and form analyses were computed with a bootstrap test on the shape distance between male and female group means (10,000 iterations).

Visualization

To visually present shape information in a way that provides value to facial surgeons who perform GFS, a

Fig. 1. The facial regions and landmarks used in this study visualized on an example subject. Area regions: **(A)** forehead, **(B)** brow, **(C)** nose, **(D)** cheek, **(E)** lips, **(F)** chin, **(G)** jaw. Curves **(H)** midline sagittal curve, **(I)** nasion axial curve, **(J)** pronasale axial curve, **(K)** nose sagittal curve, **(L)** brow sagittal curve. Landmarks: Nasion (n), pronasale (prn), subnasale (sn), labiale superius (ls), labiale inferius (li), gnathion (gn), alar curvature point (ac).

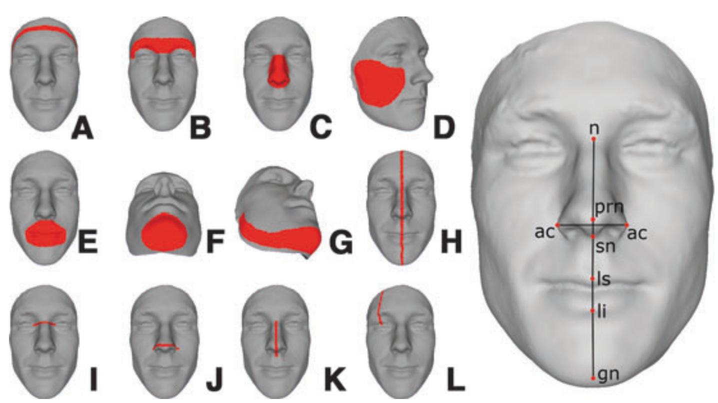


Table 1. Euclidean distance measurements between landmark pairs

Landmark pair	*Male mean (SD)*	*Female mean (SD)*	*Mean % difference*	*Cohen's* D
Nasal base width (ac-ac)	35.8 (2.6)	33.1 (2.3)	8.3	1.12
Nasal height (n-sn)	56.6 (3.8)	54.8 (3.8)	3.4	0.49
Nasal dorsum length (n-prn)	49.4 (3.8)	47.5 (3.6)	5.1	0.66
Nasal tip projection (sn-prn)	21.0 (2.0)	20.2 (1.9)	4.2	0.43
Lip height (li-ls)	14.3 (3.3)	14.3 (2.8)	0.4	0.02
Philtrum length (sn-ls)	16.5 (2.7)	14.3 (2.4)	15.4	0.87
Chin height (gn-li)	43.7 (3.9)	39.3 (3.7)	11.3	1.18

The effect of sex is highly significant ($p < 0.0001$) for all measurements except for lip height ($p = 0.72$). All measurements, apart from Cohen's *D* and % difference, are reported in units of mm.

deformation field representing the mean difference between male and female facial shapes is rendered as a ''heat map.'' In another approach to visualizing mean differences in male and female facial shape, we deform an example subject's face along an axis of sex difference. Both approaches show mean shape differences as determined by the statistical analysis.

Results

Euclidean distances

Linear distances are reported for features of the face that are directly surgically relevant and can be measured intraoperatively on surface anatomy (Table 1). For each distance measurement apart from lip height ($p = 0.72$), the effect of sex was significant ($p < 0.0001$). All effects were in the same direction of the feature, being larger in males than in females. The largest standardized sex effects were found in chin height, nasal base width, and philtrum length.

Size

Male faces were found to be 7.3% larger than female faces on average (Table 2). The average male facial size from this sample was greater than 98% of female subjects. Likewise, for each facial sub-region and curve, the effect of sex on size was significant ($p < 0.0001$) and in the same direction (males larger than females). However, the magnitude of the effect differed among regions. The largest standardized sex effects were found in the chin and the pronasale axial curve. Although significantly different, the smallest effects were found in the nose sagittal curve and the forehead.

Table 2. Effect sizes describing the magnitude of sex effects on facial size, shape, and form in different facial regions

Facial region	*Mean % size difference*	*Sex-size Cohen's* D	*Sex-shape* R^2	*Sex-form* R^2
Full	7.3	2.17	0.06	0.30
Forehead	6.0	1.54	0.04	0.27
Brow	6.8	1.64	0.10	0.29
Nose	8.5	1.91	0.06	0.22
Cheek	7.4	1.96	0.05	0.27
Lips	8.0	1.49	0.02	0.17
Chin	9.4	1.98	0.03	0.25
Jaw	7.7	2.00	0.06	0.32
Midline sagittal curve	7.4	1.78	0.05	0.28
Nasion axial curve	9.0	1.18	0.14	0.19
Pronasale axial curve	11.1	2.13	0.06	0.31
Nose sagittal curve	5.9	0.97	0.02	0.12
Brow sagittal curve	6.8	1.41	0.13	0.23

The effect of sex is highly significant ($p < 0.0001$) in terms of size, shape, and form in every listed facial region and curve.

Shape

The average male facial shape was significantly different than the average female facial shape ($p < 0.0001$). Sex accounted for 6% of total shape variance in the full face. For every facial region, the effect of sex on shape was significant ($p < 0.0001$). The magnitude of the effect differed among regions (Table 2). The regions in which sex accounted for the greatest fraction of total shape variance were the nasion axial curve, the brow sagittal curve, and the brow. Although significant, the regions in which sex accounted for the lowest fraction of total shape variance were the lips, the nose sagittal curve, and the chin. Table 2 shows the full results of the sex-shape analysis.

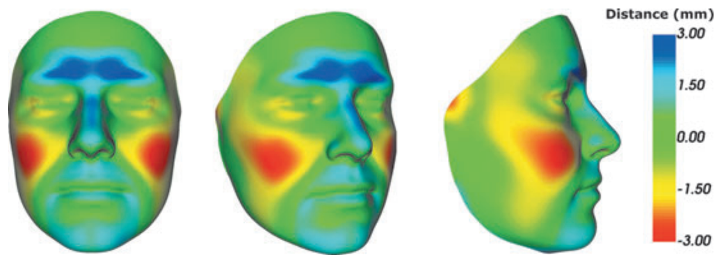
Form

Form measurements represent the combination of both size and shape. The average male facial form was observed to be different than the average female facial form ($p < 0.0001$), and sex was able to explain 30% of total form variance in the overall face. For every facial region, the effect of sex on form was significant ($p < 0.0001$), and the magnitude of effect differed among regions (Table 2). The regions in which sex accounted for the greatest fraction of total form variance were the jaw, the pronasale axial curve, and the full face. Although significant, the regions in which sex accounted for the least fraction of total form variance were the nose sagittal curve and the lips.

Visualization of facial shape

Figure 2 shows the average female facial shape colored according to the difference between the average male and female facial shapes. This visualization only shows shape differences, not size differences, by first scaling

Fig. 2. The average female facial shape colored according to the difference between the average male and female facial shapes (excluding size differences). Color corresponds to the inner product of the difference vector with the unit normal vector of the facial surface at each point. Therefore, positive values indicate that the facial surface would be pushed outward in a more masculine facial shape, whereas negative values indicate the opposite.



the faces to the overall mean centroid size. Additional shape visualizations with vector and magnitude sex differences for each of the subregions and curves are included as Supplementary Data.

The visualizations show that the female superior forehead projects outward, whereas the male inferior forehead (brow) projects outward. The male glabellar region has greater prominence in comparison to the female, and this prominence continues throughout the nose. In addition, the male jaw exhibits greater anterior, lateral, and inferior projection compared with the female jaw. The female cheek has greater projection at the anterior and central cheek, with tapering along the zygomatic arch. The greatest differences in the lips were found in the soft tissue areas directly above the superior lip and directly below the inferior lip, with the lips themselves showing little shape difference between the sexes.

Figure 3 shows an alternative approach to visualizing the same male/female axis of shape difference. An example subject was transformed to have a more masculine and more feminine facial shape. The same masculine/feminine shape characteristics can be seen to change as the subject face deforms. A linguistic summary of the observed shape differences is provided in Table 3. In addition, Table 4 lists typically performed procedures encompassing GFS and highlights the procedures that are directly supported by this analysis.

Discussion

In surgeries that alter the entire face, such as GFS, a sophisticated 3D assessment of facial characteristics is essential. In this study, we used 3D facial surface scans to quantify and depict the effect of sex on adult facial size and shape. In summary, sex accounts for only 6% of facial shape variance. However, it accounts for 30% of facial form variance, demonstrating that male–female facial size differences are a critical factor to consider in GFS.

Fig. 3. Top: An example subject (center column) that has been transformed to have a more masculine (right) and more feminine (left) shape, leaving overall size unchanged. The shape distance between each column is equal to the magnitude of the shape distance between the averaged female and male facial shapes. Bottom: The same shape transformation process applied to the nose region of the same subject.

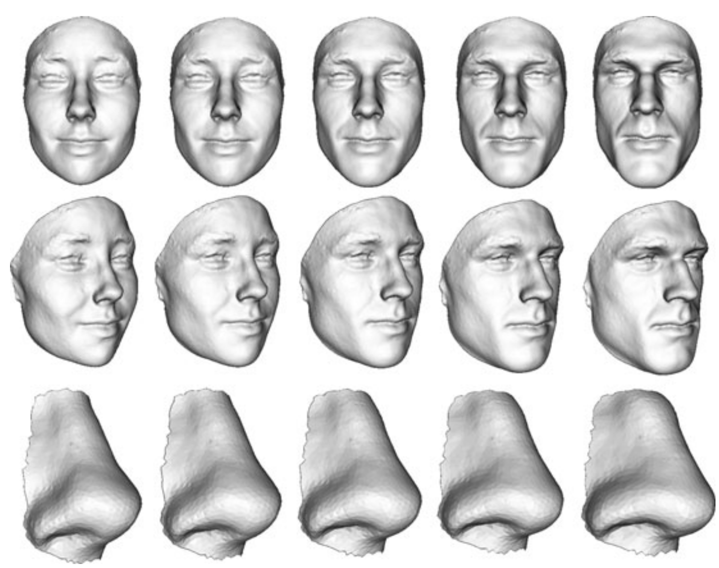


Table 3. Male and female facial sex characteristics of significant difference in three-dimensional analysis

Male facial characteristics	*Female facial characteristics*
Larger face	Smaller face
Nasofrontal and brow prominence	Minimal nasofrontal and brow prominence
Angled, strong nasofrontal configuration	Curved, soft nasofrontal configuration
Upper forehead less prominent	Upper forehead more prominent
Larger, more projected nose	Smaller, less projected nose
Nasal tip broad and not up-rotated	Nasal tip small and up-rotated
Wider nostril size	Narrower nostril size
Longer upper lip	Shorter upper lip
Flat cheeks	Fuller cheeks
Wide, long jaw and chin	Tapered, narrower, and shorter jaw and chin

Among the studied curvatures of the face, the pronasale axial curve, which represents the nasal projection and tip size, had the greatest standardized effect of sex by size, followed by the nasion axial curve, which represents the nasal projection between the eyes. In evaluations of shape, sex explained the greatest proportion of variance in the brow region and again in the nasion axial curve. Combining size and shape, differences in form are notable in the jaw, brow, forehead, cheeks, lips, and chin.

Euclidean distance comparisons show upper lip philtrum length, nasal base width, and chin height to exhibit significant sex difference. Collectively, these findings objectively suggest that alterations of the mandible and chin, cheek, lips, brow and forehead, and nose are potentially essential for appropriate gender transformation in GFS. Surgical alterations that affect both size and shape should be considered and may provide a fitting framework for surgical planning.

Table 4. Typically performed procedures encompassing gender-affirming facial surgery

GFS for feminization	*GFS for masculinization*
Upper face	Upper face
Hairline advancement	**Masculinizing frontal cranioplasty**
Temporal recession reduction	
Feminizing frontal cranioplasty	
Brow lift	
Midface	Midface
Cheek augmentation	**Cheek augmentation**
Rhinoplasty (reduction)	**Rhinoplasty (augmentation)**
Alar base narrowing	**Buccal fat removal**
Lip lift	
Lower face	Lower face
Lip augmentation	**Mandible augmentation**
Lip lift	Submental liposuction
Mandible reduction	Chondrolaryngoplasty
Submental liposuction	
Chondrolaryngoplasty	
Facial skin	
Face lift	
Neck lift	

The bolded procedures are supported by anatomical comparative data from this analysis. All procedures that are not bolded are not directly assessed by these data, so a conclusion regarding sex difference cannot be made.

GFS, gender-affirming facial surgery.

Foundational perception studies have demonstrated the correlation between facial sex characteristics and gender perception. Brown and Perret's 1993 study correlated individual facial features with observer gender perception by altering specific features.[15] In their study, all facial features, except the nose, carried information about gender.

Moreover, when female facial features were placed on a male facial prototype, changes to the jaw, brows, eyes, and chin resulted in a significant change in observers' gender perception. Subsequently, Spiegel showed that a reduction of the brow prominence using image manipulation correlated with observer perception of a more feminized face.[16] Our findings support these previous works while providing a precision, data-driven, and 3D framework from which to support and guide GFS.

Although several common GFS surgical components, such as mandible reduction and frontal cranioplasty,[16–18] receive objective support from our statistical analysis of facial sex differences, this study also identifies several important areas for GFS modification that are commonly not performed. For example, the size and shape of the nose proved to be significantly different between sexes, suggesting that the nose may be more important than previously suggested. Likewise, the cheeks and lips are important areas of facial sex difference that could be assessed for appropriate alteration. Our results suggest that these and other procedures should be considered for GFS patients (Table 4).[8]

Although the analysis indicates that both size and shape are important differentiators of the male and female face, size differences are most evident in the jaw, cheek, and nose, whereas shape differences are most evident in the nasofrontal area. Recognizing that both size and shape are implicated in sex differences can have important practical consequences in GFS. Surgical alteration of only either shape or size may likely produce a less effective gender modification. Moreover, these results suggest that in some cases, effective gender modification may be achieved by over-correcting either size or shape. For example, if functional or other concerns prevent a surgeon from reducing jaw size by the desired amount in a feminization procedure, it may be possible to over-feminize shape changes (e.g., making the chin less square) to achieve the desired effect.

Limitations

Our study has several limitations and must be interpreted in the context of the study design. Despite the large number of subjects, the ethnic and racial diversity of our sample is limited. As self-identified race and ethnicity have some association with facial form, a more diverse dataset would be beneficial for future analyses.[19] Due to imaging technology limitations, we were unable to analyze differences in eyebrow hair, hairline, and skin surface texture.

The facial shape and size differences observed in this study may or may not influence observer- and self-assessed gender perception. Future 3D-based perception studies may clarify the relevance of these findings. Finally, each face is unique, and the applicability of these findings should be weighed with the patient's facial features and individualized and patient-centric goals. Surgical planning should strongly consider a cohesive, guided, natural, and individualized approach that emphasizes facial attractiveness.[20]

Conclusion

GFS constitutes a patient-specific set of procedures aimed at altering facial gender affiliation. Two fundamental questions in GFS are how to determine which surgical procedures to undertake and how to assess the degree of change necessary to achieve a transformed facial gender affiliation. Although each face is individual, consideration should be given to both size and shape of each facial feature.

We quantitatively showed that many areas of the face are associated with sex differences, with the strong relevance and support of frontal contouring and cranioplasty, rhinoplasty, mandible and chin alteration, lip enhancement and lifting, and cheek alteration as high yield GFS procedures.

Authors' Contributions

All authors provided substantial contributions, drafting, and revising of the work, providing final approval of the article, and are accountable for all aspects of the work.

Author Disclosure Statement

Authors J.J.B., J.D.A, D.C.K., B.H., N.D.F., and R.S. are affiliated with Deep Surface AI, Inc., a company specializing in 3D facial analytics and morphing.

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Supplementary Material

Supplementary Data

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