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Midface Skeletal Sexual Dimorphism: Lessons Learned from Advanced Three-dimensional Imaging in the White Population

Abdallah Abushehab, MD*
Jess D. Rames, MD*
Sara M. Hussein, MD*
Alexandre Meire Pazelli, MD*
Tori A. Sears, MS†‡
Adam J. Wentworth, MS, MD†‡
Jonathan M. Morris, MD†‡
Basel A. Sharaf, MD, DDS*

Background: Facial shape is significantly influenced by the underlying facial bony skeleton. Sexual dimorphisms in these structures are crucial for craniofacial, aesthetic, and gender-affirming surgery. Previous studies have examined the orbits and upper face, but less is known about the midface. This study aimed to elucidate the sexual dimorphism in the midface region, focusing on the maxilla and zygomatic bones.

Methods: A retrospective review was conducted using facial computed tomography scans from 101 White patients aged 20–79 years, using Materialise Mimics and 3-Matics for segmentation and 3D reconstruction. Measurements and statistical shape modeling of the midfacial skeleton were performed.

Results: Our results show a distinct sexual dimorphism in the midfacial skeletal structure across all age groups. Women typically had a narrower bizygomatic width by 1.5 mm ($P = 0.04$), a shallower maxillary depth by 1.6 mm ($P < 0.01$), and a midfacial vertical height that was 4 mm shorter than that of men ($P = 0.018$). In contrast, men exhibited a greater distance between the frontozygomatic sutures by 5.4 mm ($P < 0.01$), a 3-mm greater interorbitale distance ($P < 0.01$), and a 2.1-mm wider infraorbital foramina distance ($P = 0.007$). There were no significant differences in the pyriform and maxillary angles ($P = 0.15$ and $P = 0.52$, respectively).

Conclusions: Our analysis of midfacial skeletal anatomy revealed sexual dimorphism differences. Men exhibited more pronounced facial features than women, with a broader horizontal midfacial skeleton, a longer midfacial vertical height, and greater maxillary depths compared with women. *(Plast Reconstr Surg Glob Open 2024; 12:e6215; doi: 10.1097/GOX.0000000000006215; Published online 9 October 2024.)*

INTRODUCTION

Facial aesthetics and reconstructive surgery have long been influenced by the anatomical understanding of facial structures. The midfacial skeleton, composed of the maxilla and zygoma, plays an important role in determining facial contour and appearance.[1] Gender differences in skeletal anatomy, known as sexual dimorphism, are of particular interest due to their implications in planning craniofacial reconstruction and aesthetic and transgender surgery.[2]

Historically, research has extensively explored dimorphism with a focus on the impact of sexual dimorphism on facial soft-tissue appearance across various age groups. For instance, Kesterke et al demonstrated that craniofacial soft-tissue sex differences emerge at an early age and become more distinct after puberty.[3] Similarly, Skomina et al delved deeper into the facial soft tissue, finding that facial sexual dimorphism is influenced by multiple parameters, including age, height, and body mass index (BMI).[4] On the other hand, Mendelson et al investigated the effects of aging on sexual dimorphism in the bony orbits and the anterior maxilla. He reported that, as aging occurs, the anterior maxillary wall retracts in relation to the bony orbit; however, there was no significant difference between men and women regarding these changes in the maxillary wall with age.[5] Other research has focused on the lower face. For example, Garvin et al[6] found significant sexual dimorphism in the morphologies of the brow ridge and the chin, pointing out that men

*From the *Division of Plastic and Reconstructive Surgery, Mayo Clinic, Rochester, Minn.; †Division of Neuroradiology, Anatomic Modeling Lab, Department of Radiology, Mayo Clinic, Rochester, Minn.; and ‡Anatomic Modeling Lab, Department of Radiology, Mayo Clinic, Rochester, Minn.*

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generally exhibited larger and more projecting brow ridges and chins compared with women. Moreover, Paetz et al[7] studied temporal bone sexual dimorphism from birth to adulthood. Their analysis revealed that the temporal bone and inner ear structures not only differ in size between men and women but also follow different rates and extents of growth, indicating that the temporal bones in men start larger and grow faster compared with those in women.

However, the literature on midfacial skeletal dimorphism, particularly the maxilla and zygomatic bones, remains relatively sparse. Few studies have focused on sexual dimorphism in the midface area from the early postnatal period to childhood,[8,9] or presented different viewpoints of the midface, such as the study by Przystańska et al[10] on sexual dimorphism in maxillary sinuses in individuals aged 18 or younger. However, a knowledge gap exists in three-dimensional (3D) analysis of midfacial skeleton in sexes.

For facial plastic surgeons, these sexual dimorphisms are crucial for the planning and execution of both reconstructive and aesthetic procedures. Delineating gender differences in midfacial bony contour helps further our understanding and improve surgical planning of craniofacial, aesthetic, and transgender procedures.[11,12] With the advent of high-resolution computed tomography (CT) and 3D modeling software, novel approaches to exploring these anatomical nuances with high fidelity have emerged. In this study, we aim to analyze sexual dimorphism in the midfacial skeletal anatomy, specifically focusing on bony morphological distinctions between male and female maxilla and zygomatic bones.

METHODS

Data Acquisition

We conducted a retrospective analysis using all available CT scans of the skull (head, neck, and maxillofacial regions) at our institution from January 2011 to December 2023. All adult patients (≥20 years old) with White ethnicity were included. Patients with history of craniofacial trauma, tumors, orthognathic surgery, or active orthodontic intervention were excluded. Only CT scans with 1 mm or less slices were included. Scans with inferior quality or motion artifact were excluded.

3D Modeling

Digital Imaging and Communications in Medicine files for each CT scan were imported from our institution's imaging database. Facial skeleton segmentation and 3D reconstruction were performed using the Materialise Mimics software (version 25.0, Materialise NV, Belgium). Segmented models were standardized by isolating the mandibular bone and the top of the cranium (the Calvaria). All 3D meshes were then exported as STL files to Materialise 3-Matics software for further refinement.

Data Collection Using 3-Matics Software

A segmented, clean version of each patient's facial skeleton was obtained using 3-matic software, which allowed for standardized manual measurements of each patient's midface structures. Eight anthropometric cephalometric measurements were taken to assess horizontal, vertical, and depth measurements of the maxillary and zygomatic bones to accurately detect differences in sexual dimorphism. Horizontal measurements included the bizygomatic width (the horizontal distance between the most lateral points of the zygomatic bones), the frontozygomatic suture distance (the distance between the frontozygomatic sutures, marking the junction of frontal and zygomatic bones), the interorbitale distance (the horizontal span between the most inferior points of infraorbital rims), and the infraorbital foramen distance (the horizontal distance between the infraorbital foramina). The vertical measurement included the vertical height from the anterior nasal spine to the nasion (the vertical height of the midfacial skeleton). For depth, the distance from the anterior nasal spine to the posterior border of the maxilla (maxillary depth assessing the anteroposterior dimension of the maxilla). The pyriform angle and the maxillary angle were measured to provide information on the overall shape and orientation of the maxilla (Fig. 1).

Takeaways

Question: How does the midfacial skeletal structure differ between men and women?

Findings: Our study used advanced 3D imaging to analyze facial computed tomography scans from 101 White patients, identifying significant sexual dimorphism in the midfacial skeleton. Men generally showed broader and deeper facial structures, whereas women had narrower and shallower skeletal features.

Meaning: This study underscores the importance of recognizing sex-specific facial skeletal features to optimize outcomes in craniofacial surgical planning.

Interrater Reliability

To validate the methods used for collecting the 3D CT measurements, two independent researchers (AAS and AMP) collected the measurements for 10 randomly selected patients. The interrater reliability of the measurements was assessed using a two-way mixed-effects model, with absolute agreement.

Statistical Analysis

Demographic characteristics and cephalometric measurements were evaluated for population-level distributions by gender. The Kolmogorov-Sminov test was used to assess normality, and the Levene test for the variance of the data. The data exhibited a normal distribution. Summary statistics were presented as means with SD. Continuous distributions were compared by gender using independent Student *t* tests. Correlation analysis was conducted to investigate the relationships between the cephalometric measurements, age, and BMI. To assess the strength and direction of the linear relationships between the continuous variables, Pearson correlation coefficient (r) was calculated. The level of significance was set at $\alpha = 0.05$ for all statistical tests. All

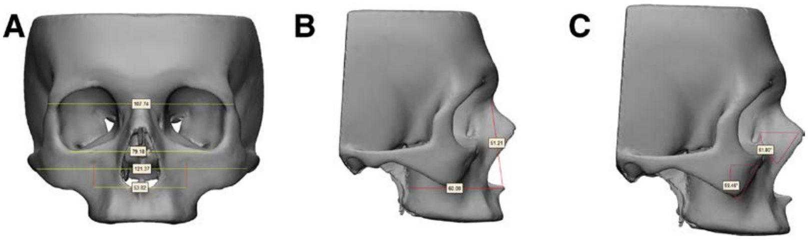

Fig. 1. Diagrams of measurements. A, Anterior view of the measurements showing the bizygomatic width (the horizontal distance between the most lateral points of the zygomatic bones), the frontozygomatic suture distance (the distance between the frontozygomatic sutures, marking the junction of frontal and zygomatic bones), the interorbitale distance (the horizontal span between the lowest points of both orbits), the infraorbital foramen distance (the horizontal separation between the infraorbital foramina). B, A lateral view of the measurements showing the midface vertical height from the nasal spine to the nasion (offering insights into the vertical growth patterns of the midfacial skeleton) and the depth of the maxillary bone measured from the nasal spine to the posterior border of the maxilla (assessing the anteroposterior dimension of the maxilla). 1c. A lateral view of the measurements showing the pyriform angle and the maxillary angle (providing information on the overall shape and orientation of the maxilla).

Table 1. Patient Demographics

	Total	Female	Male
No. patients	101	47	54
No. youngs (20–39 y)	29	14	15
No. middle age (40–59 y)	36	17	19
No. older (60–79 y)	31	14	17
Average age by year (SD)	50.3(17)	50.5(17)	50.9(17)
Average BMI, kg/m^2 (SD)	30.5(7)	29.9(7)	31(7)

the analyses and figure creation were performed using IBM SPSS Statistics (version 29).

Surface Contour Comparisons

Statistical shape modeling (SSM) software (Mimics Innovation Suite) was used to create composite averages of all male and all female 3D facial skeleton models across the different age groups: young adults (20–39 years old), middle-aged (40–59 years old) and older adults (60–79 years old). An averaged SSM model for young, middle, and older ages was generated for both men and women. Averaged SSMs were then manually aligned according to the world coordinate system using the built-in "Global Registration" feature for each age group. Heatmaps were subsequently generated using 3-Matic software to display vector-based surface topology discrepancies, using the female SSM as a reference. Areas highlighted in blue and red correspond to positive and negative surface deviations, respectively.

RESULTS

A total of 101 patients were included: 47 women and 54 men, with an average age of 50.3 ± 17 years and an average BMI of 30.5 kg per m^2 (ranging from 18.5 to 59). Patients were categorized into three groups, based on age: young adults (20–39 years), middle-aged (40–59 years), and older adults (60–79 years) (Table 1). A comprehensive analysis of midfacial bony measurements across all age groups revealed marked sexual dimorphism. On average, women demonstrated a narrower bizygomatic width compared with men (1.5 mm, $P = 0.04$), shallower maxillary depth by 1.6 mm ($P < 0.01$), and a midfacial vertical height that is 4 mm shorter than that of men ($P = 0.018$). In contrast, men exhibited broader distances between the frontozygomatic sutures (5.4 mm, $P < 0.01$), interorbitale distance (3 mm, $P < 0.01$), and a distance between the infraorbital foramina (2.1 mm, $P = 0.007$) compared with women. The pyriform angle and the maxillary angle showed no significant difference ($P = 0.15$ and $P = 0.52$, respectively; Table 2).

When stratified by age, each group displayed distinct patterns of sexual dimorphism. The young group showed a significantly increased midfacial vertical height in men compared with women by 3.6 mm ($P = 0.002$) and a more acute pyriform angle, with a mean difference of 4.8° ($P = 0.03$). The middle-aged group showed statistically significant differences in almost all parameters measured except for the pyriform and maxillary angles. Men exhibited statistically significant increases in frontozygomatic suture distance, interorbitale distance, infraorbital foramina distance, midfacial vertical height, and maxillary depth, with mean differences of 8.7 mm, 4.6 mm, 4.6 mm, 2.8 mm, and 2.7 mm, respectively ($P < 0.05$), compared with women. However, bizygomatic width showed no statistically significant difference between sexes ($P > 0.05$). In the older age group, men demonstrated wider frontozygomatic suture distance, interorbitale, midfacial vertical

Table 2. Midface Measurements for the Total Population (All Age Groups)

Average	Female	Male	Mean Differences	P
Bizygomatic width/mm (SD)	115.2(4)	116.8(5)	−1.5	**<0.046**
Frontozygomatic suture distance/mm (SD)	102.5(4)	107.9(3)	−5.4	**<0.01**
Interorbitale distance/mm (SD)	76(5)	79(4)	−3	**<0.01**
Infraorbital foramina distance/mm (SD)	49.7(4)	51.9(3)	−2.1	**0.07**
Midface vertical height/mm (SD)	48.6(3)	52.6(3)	−4	**0.018**
Maxillary depth/mm (SD)	53.4(3)	55(3)	−1.6	**<0.01**
Pyriform angle/degree (SD)	54.9(6)	53(6)	1.7	0.15
Maxillary angle/degree (SD)	61.8(5)	62.5(5)	−0.69	0.52

Values in boldface are statistically significant ($P < 0.05$).

Table 3. Midface Measurements in the Young Age Group

Young Age Group				
	Female	Male	Mean Difference	P
Bizygomatic width/mm (SD)	116.4(2.8)	116.5(5)	−0.1	0.47
Frontozygomatic suture distance/mm (SD)	105.9(3)	106.8(4)	−0.85	0.55
Interorbitale distance/mm (SD)	78.7(5)	79.7(4)	−0.85	0.6
Infraorbital foramina distance/mm (SD)	50.5(4)	50.9(4)	−0.41	0.8
Midface vertical height/mm (SD)	48.4(2)	52.1(3)	−3.6	**0.002**
Maxillary depth/mm (SD)	56(3)	55.5(4)	0.44	0.75
Pyriform angle/degree (SD)	58.4(5)	53.6(6)	4.8	**0.03**
Maxillary angle/degree (SD)	61(6)	63.5(5)	−2.4	0.23

Values in boldface are statistically significant ($P < 0.05$).

Table 4. Midface Measurements in the Middle Age Group

Middle Age Group				
	Female	Male	Mean Difference	P
Bizygomatic width/mm (SD)	114.3(5)	116.8(4)	−2.5	0.077
Frontozygomatic suture distance/mm (SD)	99.6(3)	108.3(3)	−8.7	**<0.001**
Interorbitale distance/mm (SD)	74.4(4)	79.1(4)	−4.6	**0.005**
Infraorbital foramina distance/mm (SD)	48.1(3)	52.8(3)	−4.6	**<0.001**
Midface vertical height/mm (SD)	49.6(3)	52.4(2)	−2.8	**0.013**
Maxillary depth/mm (SD)	52.5(2)	55.3(3)	−2.7	**0.01**
Pyriform angle/degree (SD)	53.8(6)	53.9(5)	−0.07	0.9
Maxillary angle/degree (SD)	61.4(5)	60(4)	1.4	0.36

Values in boldface are statistically significant ($P < 0.05$).

Table 5. Midfacial Measurements in the Older Age Group

Older Age Group				
	Female	Male	Mean Difference	P
Bizygomatic width/mm (SD)	115.1(4)	117.3(4)	−2.2	0.09
Frontozygomatic suture distance/mm (SD)	102.3(2)	108.6(2)	−6.2	**<0.001**
Interorbitale distance/mm (SD)	75.4(4)	78.7(3)	−3.2	**0.02**
Infraorbital foramina distance/mm (SD)	50.7(4)	51.8(2)	−1	0.39
Midface vertical height/mm (SD)	47.6(2)	53.3(3)	−5.7	**<0.001**
Maxillary depth/mm (SD)	51.9(3)	54.5(3)	−2.6	**0.023**
Pyriform angle/degree (SD)	52.6(6)	51.7(5)	0.91	0.67
Maxillary angle/degree (SD)	63(4)	64.4(6)	−1.4	0.45

Values in boldface are statistically significant ($P < 0.05$).

height, and maxillary depth compared with women, with mean differences of 6.2 mm, 3.2 mm, 5.7 mm, and 2.6 mm, respectively ($P < 0.05$). No statistically significant differences were observed between men and women in infraorbital foramina distance, bizygomatic width, pyriform angle, and maxillary angle (Tables 3–5).

Interrater Reliability Analysis

The analysis revealed good reliability for both single and average measures, showing an intraclass correlation coefficient greater than 0.9 for both, with a P value of less than 0.001. These results indicate an excellent agreement in measurements between the two researchers (A.A.S. and A.M.P.).

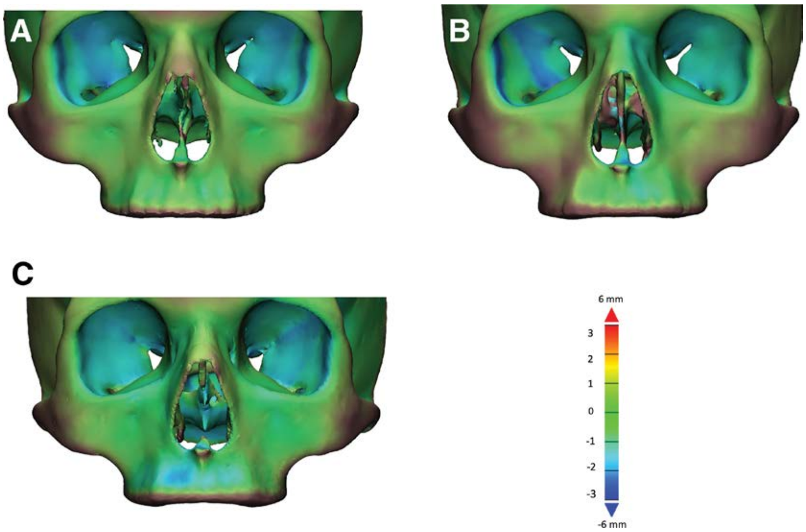

Fig. 2. Heat map of the midface, showing the intensity of differences between average male and female skulls. Anterior view for young age group (A), middle age group (B), and older age group (C). The red color in the index scale represents the areas where the male skull protrudes outward relative to the female skull, while the blue color represents the areas where the male skull is recessed inward compared with the female skull. Units are in millimeters (D).

Correlation Analysis by Age and BMI

Men

A positive correlation was observed for the frontozygomatic suture distance with age (r = 0.289, $P = 0.034$), indicating that this measurement may increase as age progresses in the male group. Other facial measurements did not exhibit a statistically significant association with age. On other hand, there was a negative correlation between midfacial vertical height and BMI (r = -0.38 $P = 0.006$), indicating that as BMI increases, midfacial vertical height tends to decrease. Other facial measurements did not exhibit a statistically significant association with BMI.

Women

The distance between frontozygomatic sutures, maxillary depth, and the pyriform angle were negatively correlated with age (r = -0.487, $P < 0.001$; r = -0.446, $P = 0.002$; and r = -0.305, $P = 0.037$, respectively), indicating a decrease in these measurements as women age. This suggests that certain facial dimensions in women tend to change more with age than those in men.

The correlation analysis with BMI in women showed no statistically significant associations for the measured variables, indicating that within the scope of this study, BMI did not have a discernible relationship with facial measurements in the female group.

Statistical Shape Modelling

The results of the SSM software are represented by combining all female CT images together and all male CT images together, then classifying them based on age group (Figs. 2–5). The results showed that in the midfacial skeleton area, the differences between men and women (where the male skeleton is wider and broader) increase with age and reach their maximum in the middle age group. Subsequently, the results indicated a decrease in sexual dimorphism differences at the older age level, which aligns with our statistical results demonstrating that the maximum differences in sexual dimorphism occur in the middle age group.

DISCUSSION

This study highlights differences in midfacial skeletal anatomy due to gender dimorphism using advanced 3D imaging and modeling techniques. We have chosen a homogeneous White population to avoid confounders related to ethnic influences on facial skeletal morphology. Our findings reveal patterns of sexual dimorphism across various cephalometric parameters, aligning with and extending previous research in this domain.[13,14]

Advancements in 3D imaging have facilitated a more nuanced understanding of sexual dimorphism in craniofacial structures beyond conventional two-dimensional measurements.[15,16] Shui et al[17] demonstrated how 3D shape analysis is a powerful tool for understanding facial structure variations and their implications in forensic science for sex estimation and in the broader field of facial reconstruction. This approach aligns with our methodology of employing 3D morphometric analyses to detect sexual dimorphism features in the midfacial skeleton.

Consistent with our results, several studies have documented the presence of sexual dimorphism in facial bone structure using 3D imaging. For instance, Imaizumi et al[18] observed significant differences in the 3D shape variations of the face and facial parts between men and women, identifying height-width proportion and depth as key

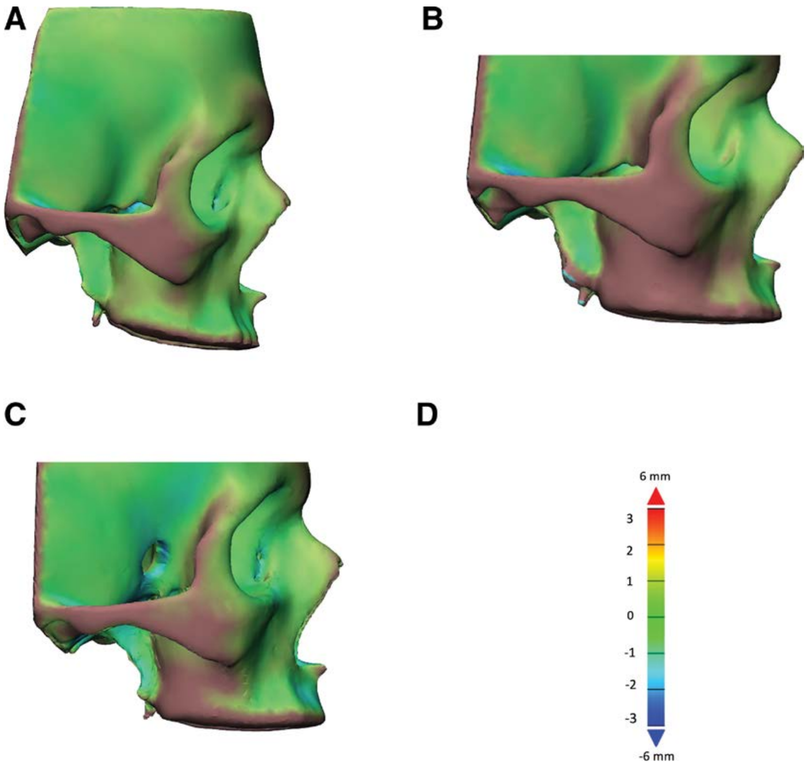

Fig. 3. Heat map of the midface, showing the intensity of differences between average male and female skulls. Lateral view for young age group (A), middle age group (B), and older age group (C). The red color index scale represents the areas where the male skull protrudes outward relative to the female skull, while the blue color represents the areas where the male skull is recessed inward compared with the female skull. Units are in millimeters (D).

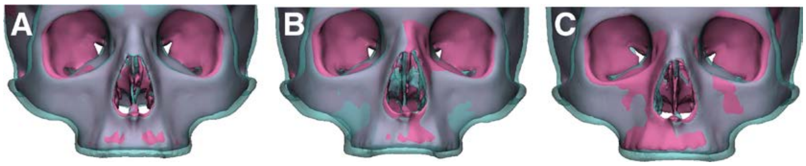

Fig. 4. Combined midface of average female and male skulls, shown in different age groups. The pink color represents the female midface, and the transparent blue represents the male midface. A, Anterior view of the young age group. B, Anterior view of the middle age group. C, Anterior view of the older age group.

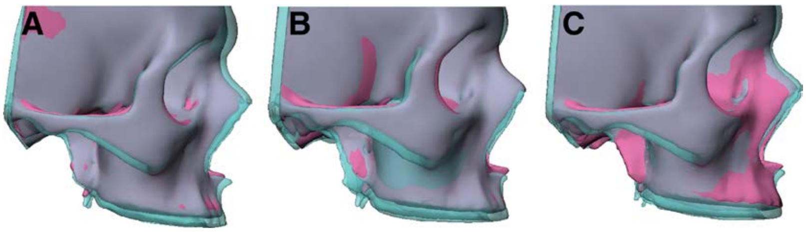

Fig. 5. Combined midface of average female and male skulls, shown in different age groups. The pink color represents the female midface, and the transparent blue represents the male midface. A, Lateral view of the young age group. B, Lateral view of the middle age group. C, Lateral view of the older age group.

factors distinguishing gender in facial structures. These findings underscore the variability in facial dimensions that contribute to sexual dimorphism, which is reflected in our analysis of cephalometric measurements. On the other hand, Liu et al[19] studied sexual dimorphism in a population of 42 White celebrities using an AI-enhanced two-dimensional approach and found that bizygomatic width and lower midface width are larger in men compared with women. These results align with our findings.

Regarding the impact of aging on facial sexual dimorphism, our study suggests that while sexual dimorphism in the midfacial skeleton is present to a lesser degree in young individuals, it becomes more pronounced by middle age and then decreases in older age. However, it is worth noting that sexual dimorphic changes in the older age group were more significant than in the younger age group. Our data also indicate that aging impacts midfacial skeletal changes in the sexes differently, with some areas showing increasing differences with age while others do not. For example, frontozygomatic suture distances became more pronounced in older age, possibly reflecting a differential rate or pattern of bone resorption or deposition compared with other areas of the face. This is further supported by the work of Skomina et al[4], who quantified facial sexual dimorphism characteristics across different age groups. They found that facial sexual dimorphism features became more pronounced with age, suggesting that biological aging processes may influence sexual dimorphism in facial structures. Also, aligning with our findings, Mendelson et al[5] have pointed out that even though there are differences in facial skeletons between genders through aging, the maxillary angle does not change. This was also supported by the findings of Toneva et al,[20] who used geometric morphometrics to assess sexual dimorphism in the viscerocranium. They emphasized facial skeletal size as a more critical determinant of sex differences than shape. Such insights are valuable for enhancing the precision of facial reconstruction and cosmetic practices.

Correlation Analysis

The correlation analysis demonstrates a clear pattern of sexual dimorphism in midfacial bony anatomy across the human lifespan from early to late adulthood. Although the overall pattern points to a generally wider and deeper facial structure in men compared with women, certain measurements such as the pyriform angle and maxillary angle remain relatively constant between genders, suggesting a degree of sexual monomorphism in these aspects as individuals age. However, the moderate strength of these associations suggests that other factors, such as soft-tissue changes not included in this study, may also play a role. On other hand, the absence of a significant relationship between facial measurements and BMI in our sample suggests its negligible effect on midface changes.

LIMITATIONS

This study, while novel in its comprehensive 3D analysis of sexual dimorphism in the midfacial skeleton, has certain limitations. The primary constraint lies in the demographic composition of our sample, which is exclusively drawn from the White population, potentially limiting the generalizability of our findings across diverse racial and ethnic groups. Further studies at our institution are underway to address gender dimorphism in other ethnicities. Additionally, the power analysis for bizygomatic width, as well as for maxillary and pyriform angles, was insufficient, indicating that a larger sample size may be required to overcome type II errors and provide more definitive conclusions regarding these specific measurements. The study's retrospective design, relying on preexisting CT scans, may introduce selection bias, as the scans were not originally intended for this research. Future studies could address these limitations by incorporating a more diverse population sample and a prospective design to further validate and expand upon our findings.

CONCLUSIONS

This study highlights important topographical skeletal sexual dimorphism in the midfacial skeleton. Using high-resolution CT scans and 3D imaging of 101 subjects, we demonstrated that men generally have a broader and deeper midfacial skeleton across their lifespan, except in areas like the pyriform and maxillary angles, where differences are not significant. In young adults, men exhibited a greater midfacial vertical height than women by 3.6 mm. Middle-aged men demonstrated larger dimensions in frontozygomatic sutures, interorbitale distance, infraorbital foramina distance, and maxillary depth, compared with women. In older individuals, these trends continued, with men displaying greater measurements in frontozygomatic suture distance, interorbitale distance, midfacial vertical height, and maxillary depth, compared with women. These findings provide further insights for plastic surgeons, emphasizing the importance of gender-specific skeletal dimorphism for surgical planning of both reconstructive and aesthetic procedures.

Basel Sharaf, MD, DDS
Division of Plastic Surgery, Department of Surgery
200 First Street SW
Rochester, MN 55905
E-mail: Sharaf.Basel@mayo.edu

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

ETHICAL APPROVAL

The study protocol received approval from our institutional review board, under the reference no.: 18-009730.

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