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Original Article

The correlations between vertical maxillary asymmetry and orbital volume in Taiwanese adults

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KEYWORDS
Orbital volume;
Patient's characteristics;
Vertical maxillary asymmetry;
Sex;
Height

Abstract *Background/purpose:* Facial asymmetry often results from discrepancies between the maxilla and mandible. As the maxilla contributes to the orbital floor and lateral wall, variations in its inclination may affect orbital morphology and volumetric symmetry. This study investigated the relationship between orbital volume (OV) and vertical maxillary asymmetry (VMA) and evaluated influencing factors such as sex, age, height, and skeletal pattern.
Materials and methods: Cone-beam computed tomography scans of 94 participants (47 men and 47 women) were analyzed. OV, right–left OV discrepancy (DOV), maxillary dimensions, and VMA (mm) were measured. VMA was defined as the vertical height difference between the right and left jugal points relative to the superior facial plane. Participants were divided into three groups on the basis of VMA: Group 1 ($-1 < VMA < 1$, normal symmetry), Group 2 ($-1 \leq VMA \leq -2$ or $1 \leq VMA \leq 2$, mild asymmetry), and Group 3 ($VMA > 2$ or < -2, significant asymmetry). Intergroup differences and correlations between OV and VMA were statistically assessed.
Results: Mean OV values were 24.25, 23.64, and 23.90 mm^3 for Group 1 ($n = 34$), Group 2 ($n = 31$), and Group 3 ($n = 29$), showing no significant intergroup differences. OV was significantly correlated with sex and height, being larger in men and taller individuals. In Group 3, DOV were positively correlated with VMA.

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Conclusion: Although overall OV and maxillary dimensions did not differ among groups, greater VMA was significantly associated with increased DOV, suggesting that enhanced maxillary asymmetry corresponds to greater orbital volumetric differences.

Introduction

The craniofacial region represents one of the most intricate and functionally significant anatomical areas of the human body. Facial attractiveness is influenced by various facial features, including the forehead, eyebrows, eyes, nose, ears, cheeks, lips, teeth, and chin. Each of these features plays a major role in overall appearance. Facial symmetry plays an essential role in establishing visual harmony, smoothness, and overall attractiveness. Facial asymmetry refers to morphological differences between the right and left sides of the face, particularly deviations from the facial midline when viewed frontally. Such asymmetry may result from abnormal growth of facial soft tissues, dentition, and skeletal structures.[1] Asymmetry in the lower face is primarily due to uneven growth between the left and right mandibles, whereas asymmetry in the middle face often results from vertical or horizontal discrepancies in the growth of the left and right maxilla.

The etiology of facial asymmetry is multifactorial, involving congenital and genetic influences, acquired factors such as trauma or orthodontic treatment, and environmental contributors including unstable occlusion, habitual unilateral mastication, and preferred sleeping positions. These factors can alter the direction and rate of facial bone growth, ultimately producing asymmetrical craniofacial morphology. Mild facial asymmetry is common among healthy individuals and is considered a normal variation of human development, generally without functional or aesthetic consequences. However, moderate to severe asymmetry may lead to malocclusion, dental misalignment, and compromised facial balance, which can influence masticatory efficiency, phonation, and psychosocial well-being. Pronounced asymmetry can distort the structural harmony of the face and impair the function of adjacent structures such as the nose, mouth, and eyes, thereby affecting both self-esteem and social interactions.[1]

The orbit is a pear-shaped cavity which contains the eyeball along with various extraocular tissues is composed of seven bones (the sphenoid, frontal, zygomatic, maxillary, lacrimal, ethmoid, and palatine bones) and is located in the upper and midfacial region.[2] The growth of the eyeball substantially influences the development of the soft tissues and bony structures surrounding the orbit. Hence, eyeball growth and movement play a key role in determining the shape and position of the orbit. Orbital development begins in the fourth week of pregnancy and rapidly progresses throughout the fetal period.[3] Research has indicated that the eyeball occupies approximately 75 % of the orbital volume (OV) in the fetus and approximately 45 % at birth.[4]

Given its anatomical proximity, the development and morphology of the orbit are closely related to those of the surrounding bones, particularly the maxilla, which contributes to the orbital floor and lateral wall. Variations in maxillary position or inclination may therefore influence orbital shape and volume. Scholars have used various approaches for OV measurement. For example, in 1873, Gayat used lead particles to fill the adult skull to measure the OV.[5] In 1933, Pan[6] used plastic pads to cushion the base of the orbit, followed by filling it with sand to obtain volume measurements. Similarly, in 1961, Alexander et al.[7] used frosted glass paper and sand to measure OV. Kennedy[8] also used elastic polymer molding technique to determine the overall weight of these substances, and the derived weight was then converted into OV. Advancements in magnetic resonance imaging (MRI) and computed tomography (CT) have enabled precise measurements of OV.[9] Recent advances in cone-beam computed tomography (CBCT) have enabled accurate evaluation of craniofacial structures and volumetric measurements with a substantially lower radiation dose compared to conventional CT.[10]

Although facial asymmetry has been extensively studied,[11–14] the relationship between vertical maxillary asymmetry (VMA) and orbital asymmetry remains poorly understood. However, limited research has explored the potential relationship between maxillary canting and orbital volumetric differences. A better understanding of this relationship is crucial for improving diagnostic accuracy and surgical or orthodontic planning in patients with facial asymmetry. Accordingly, the present study aimed to analyze CBCT images to investigate the association between VMA and orbital volume (OV) and to identify related factors such as sex, age, height, and skeletal pattern. Because the maxilla structurally contributes to the orbit, variations in its vertical inclination may influence orbital morphology and volumetric balance. We hypothesize that greater maxillary canting is associated with increased differences in orbital volume between the two sides. The null hypothesis states that no significant correlation exists between the degree of VMA and the difference OV (DOV) between the left and right sides.

Materials and methods

The participants were the same individuals enrolled in the first phase of our study.[10] CBCT images were collected from 94 participates (47 men and 47 women) at the Department of Dentistry, Kaohsiung Medical University Hospital, by using the NewTom VGi evo system (Imola, Italy). The CBCT settings were as follows: irradiation, 110 kV; current, 4.59 mA; and exposure duration, 3.5 s. During imaging

procedure, participates were placed in their maximum occlusion position. Participates were included for analysis if they met the following criteria: 1) being aged ≥20 years; 2) having a complete orbital structure; and 3) having CBCT scans with a sufficient field of view capturing the basin, porion, and glabella. Participants were excluded based on the following criteria: 1) having a history of maxillofacial trauma, 2) having congenital craniofacial anomalies or syndromes, 3) previously undergoing eye or orbital surgery, and 4) previously undergoing orthognathic surgery. Image J software (version 1.48 V) was used to analyze lateral cephalometric images obtained through CBCT. In the cephalometric analysis, skeletal relationships were classified on the basis of the ANB angle: an ANB angle of <0° was considered to indicate a skeletal Class III relationship, an ANB angle from 0° to 4° was considered to indicate a skeletal Class I relationship, and an ANB angle of >4° was considered to indicate a skeletal Class II relationship.

The following anatomical landmarks were identified: basion (Ba), nasion (N), glabella (Ga), orbitale right (Or[R]), orbitale left (Or[L]), porion right (Po[R]), and porion left (Po[L]). The midpoint between Or(R) and Or(L) was denoted as orbitale mid (Or[Mid]), and the midpoint between Po(R) and Po(L) was denoted as Porion Mid (Po[Mid]). The Frankfort horizontal line was established by connecting the Or (Mid) and Po (Mid) points. The midsagittal plane was defined as the connections between the Ga, N, and Ba points. In addition, the following reference points and planes (Fig. 1) were used for the measurements: zygomatic maxillary suture (ZM), inferior orbital foramen (IOFo), anterior nasal spine (ANS), inferior orbital fissure (IOFi), jugular (Jr), Point A (A), and Point B (B). The superior facial plane (SFP) was defined as the plane passing through the N point and parallel to the axial plane. In the measurements of maxillary dimensions, this study focused on the ZM-IOFo, ZM-ANS, and IOFi-IOFo distances. The projection from Jr to the SFP was denoted as the Jr-SFP. VMA value was determined by the vertical height discrepancy between the right and left sides of the Jr-SFP.

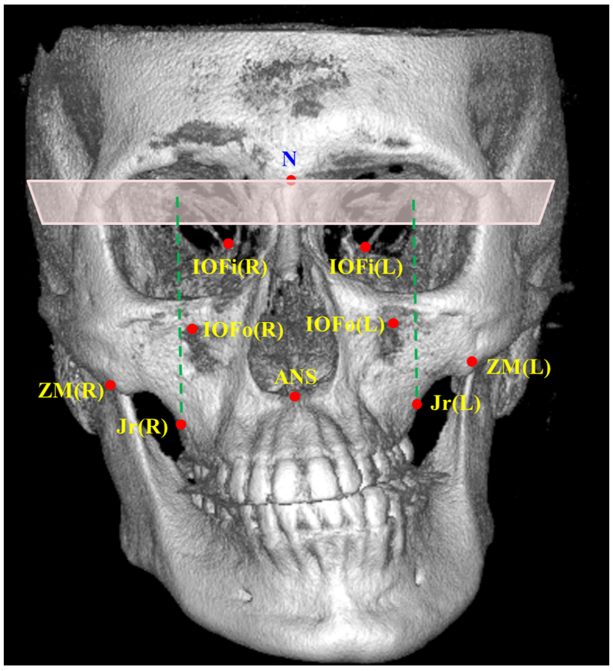

Figure 1 Landmarks: nasion (N), zygomaticomaxillary suture (ZM), inferior orbital foramen (IOFo), anterior nasal spine (ANS), inferior orbital fissure (IOFi), j6ugular (Jr), R: right side, L: left side. Superior facial plane (SFP, pink color); Jr-SFP distance (green color). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Ha et al.[15] classified facial asymmetry in adult patients and reported that the non-asymmetry group exhibited no significant maxillary dental cant, with a mean deviation of approximately 0.8° and 0.8 mm. In our clinical observation, an increase of approximately 1° in maxillary dental cant corresponds to an estimated linear discrepancy of about 1 mm. Based on this relationship, the present study adopted thresholds of ±1 mm and ±2 mm to classify the degree of vertical maxillary asymmetry (VMA). Accordingly, subjects were categorized into three groups: Group 1 (−1 mm < VMA <1 mm, normal symmetry), Group 2 (−2 mm ≤ VMA ≤ −1 mm or 1 mm ≤ VMA ≤2 mm, mild asymmetry), and Group 3 (VMA < −2 mm or VMA >2 mm, significant asymmetry).

In this study, we used the method suggested by Shyu et al.[16] to assess the OV and the difference (DOV) in the OV between the left and right sides. Specifically, the anterior boundary of the orbit was defined as a straight line connecting the inner and outer edges of the orbit, and the posterior boundary was defined by the shortest line linking the bony structures (Fig. 2). Before conducting the measurements, we imported the captured CBCT images (in Digital Imaging and Communications in Medicine format) into 3D Slicer software (version 4.11) for 3-dimensional volume rendering (Fig. 3); this rendering was achieved by adjusting the grayscale intensity levels of the voxels throughout the dataset, which thus enabled the reconstruction of the CBCT volume. Subsequently, the OV and DOV between the left and right sides were measured.

The reliability of present method was evaluated and showed that the interclass reliability coefficient varied between 0.90 and 0.97, while the intraclass reliability coefficient ranged from 0.87 to 0.98. An analysis of variance was used to examine the correlation between the three VMA patterns and OV, with Bonferroni correction applied for post hoc testing. All statistical analyses were conducted using SPSS (version 23.0; IBM, Armonk, NY, USA). A P value of < 0.05 was considered statistically significant.

Results

Table 1 presents the characteristics of 94 participates (men: 47; women: 47). On the basis of skeletal classifications, 28 participates were determined to have a skeletal Class I relationship, 32 were determined to have a skeletal Class II relationship, and 34 were determined to have a skeletal Class III relationship. The average age and height of participates in Group 1 (n = 34) were 25.06 years (range: 20—30 y) and 167.78 cm, respectively; those of participates in Group 2 (n = 31) were 29.42 years and 165.37 cm, respectively; and those of participates in Group 3 (n = 29)

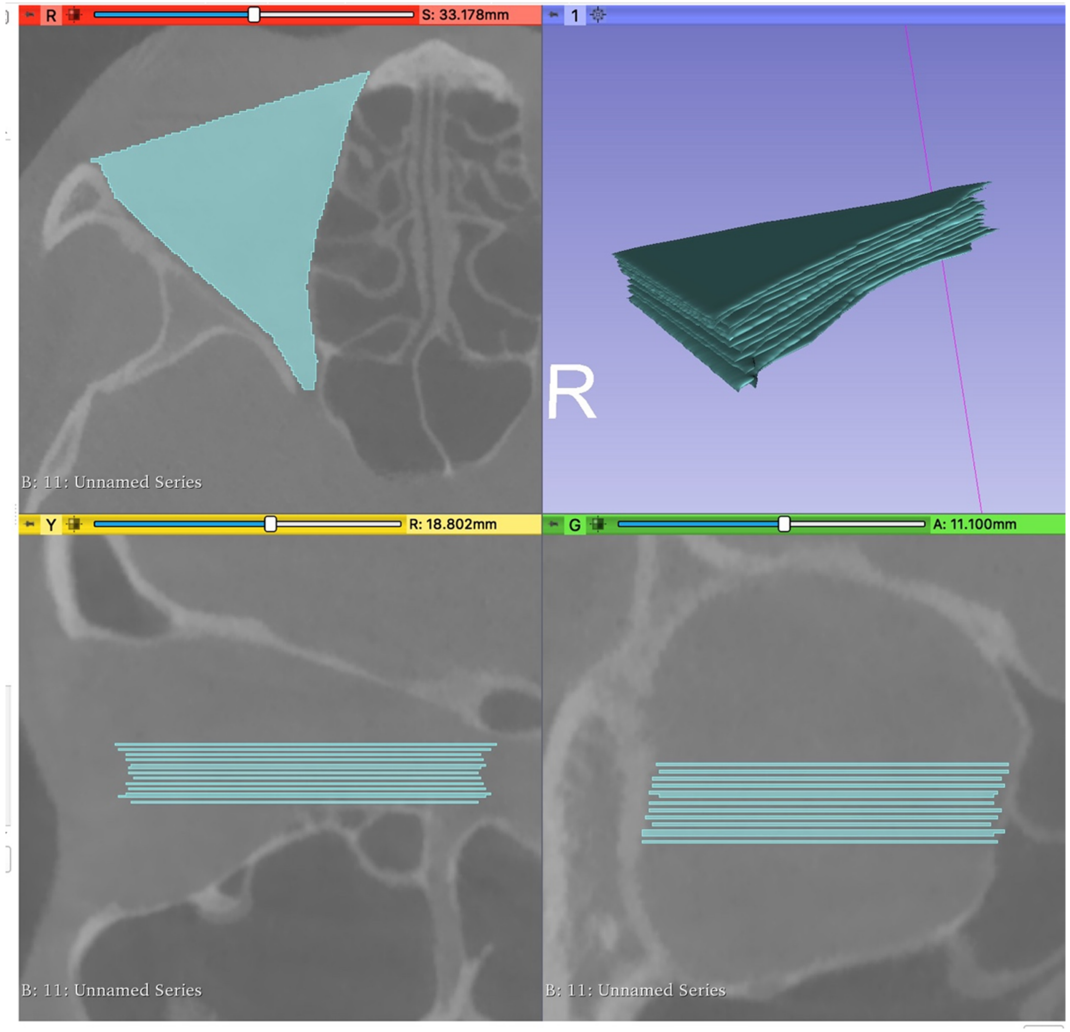

Figure 2 Orbital boundary surface and integral method. A: Axial view B: Overlapping the target region of each section. C: Sagittal view D: Coronal view.

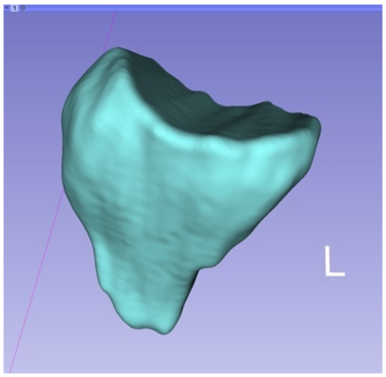

Figure 3 Orbital volume (pear-shaped) was reconstructed and measured by 3D Slicer (version 4.11).

were 25.90 years and 166.17 cm, respectively. These results indicate that participates in Group 2 were significantly older than those in Group 1. However, no significant difference in height was observed among the 3 groups. Furthermore, no significant differences in SNA, SNB, or ANB were noted among the 3 groups, although Group 3 exhibited the smallest ANB value (0.51°). The mean OV values derived for Groups 1, 2, and 3 were 24.25, 23.64, and 23.90 mm^3, respectively, indicating no significant difference among the groups. The average DOV values in Groups 1, 2, and 3 were −0.05, 0.30, and 0.41 mm^3, respectively, signifying no significant difference among the groups.

As presented in Table 2, the values of VMA derived for Groups 1, 2, and 3 were 0.01, 0.26, and 1.27 mm, respectively. Group 3 exhibited a significantly higher value than did Group 1; however, no significant differences in VMA values were observed among the 3 groups. Moreover, the right-side ZM-IOFo values derived for Groups 1, 2, and 3 were 24.02, 23.55, and 24.16 mm, respectively. The ZM-ANS values derived for Groups 1, 2, and 3 were 20.77, 50.41, and 49.89 mm, respectively. Additionally, the IOFo-IOFi distances derived for Groups 1, 2, and 3 were 44.12, 43.66, and 43.60 mm, respectively. No significant differences in right-left ZM-IOFo, ZM-ANS, or IOFo-IOFi values were observed among the 3 groups.

Table 1 Summary of characteristics in each group of vertical maxillary asymmetry (VMA).

Variables	Group 1 (n = 34)		Group 2 (n = 31)		Group 3 (n = 29)		Intergroup (*P* value)
	Mean	SD	Mean	SD	Mean	SD	
Age (year)	25.06	3.85	29.42	9.62	25.90	5.00	0.024*
Height (cm)	167.78	7.21	165.37	9.07	166.17	10.01	0.530
SNA (degree)	82.74	4.70	82.83	4.91	81.81	3.53	0.623
SNB (degree)	80.69	5.80	79.97	5.55	81.31	6.20	0.675
ANB (degree)	1.90	5.17	2.86	4.97	0.51	5.58	0.222
Right OV (mm^3)	24.22	2.69	23.79	2.11	24.11	2.37	0.758
Left OV (mm^3)	24.27	2.60	23.49	2.22	23.70	2.30	0.393
Total OV (mm^3)	24.25	2.61	23.64	2.13	23.90	2.31	0.584
DOV (mm^3)	−0.05	0.89	0.30	0.80	0.41	0.59	0.052

n: number of participant.
OV: orbital volume, DOV: difference between right and left OV.
*: Statistical significance, $P < 0.05$; Age: Group 2 > Group 1.

Table 2 Summary of maxillary dimensions in the each group of vertical maxillary asymmetry (VMA).

Variables	Group 1 (n = 34)		Group 2 (n = 31)		Group 3 (n = 29)		Intergroup (*P* value)
	Mean	SD	Mean	SD	Mean	SD	
VMA value (mm)	0.01	0.54	0.26	1.56	1.27	2.82	0.021*
Right side							
ZM-IOFo (mm)	24.02	2.94	23.55	3.09	24.16	2.55	0.688
ZM-ANS (mm)	50.77	2.76	50.41	3.00	49.89	2.67	0.467
IOFo-IOFi (mm)	44.12	2.67	43.66	2.48	43.60	3.60	0.740
Jr-SFP (mm)	63.02	4.45	62.49	4.45	63.29	4.52	0.780
Left side							
ZM-IOFo (mm)	23.94	2.90	23.22	2.93	23.42	2.35	0.553
ZM-ANS (mm)	51.07	2.91	50.20	2.71	50.02	3.13	0.309
IOFo-IOFi (mm)	44.76	3.04	43.52	2.56	43.74	3.99	0.261
Jr-SFP (mm)	63.01	4.43	62.24	4.90	62.02	5.16	0.690

n: number of participant.
ZM: zygomatic maxillary suture, IOFo: inferior orbital foramen, ANS: anterior nasal spine, IOFi: inferior orbital fissure, Jr: jugular, SFP: superior facial plane.
*: Statistical significance, $P < 0.05$; VMA value: Group 3 > Group 1.

As indicated in Table 3, DOV values were significantly correlated in the total participates (correlation coefficient: 0.241), as were the values of VMA (correlation coefficient: 0.269). We also observed significant negative sex-based correlations between the right OV, left OV, and average OV (correlation coefficients: −0.753, −0.704, and −0.739, respectively). Additionally, a significant correlation was observed between sex and maxillary asymmetry, with men exhibiting larger OVs and smaller values of VMA. Height exhibited strong positive correlations with the right OV, left OV, and average OV (correlation coefficients: 0.714, 0.701, and 0.718, respectively), suggesting that OV increases with height. Conversely, height exhibited a significant negative correlation with VMA values, implying that taller individuals tend to have smaller values of VMA values. VMA values was also significantly correlated with the right OV, left OV, average OV, and DOV (correlation coefficients: −0.211, −0.296, −0.257, and 0.252, respectively). Therefore, the null hypothesis was rejected. This suggests that as the VMA increases, the right OV, left OV, and average OV tend to decrease, whereas the DOV tends to increase. Furthermore, we noted significant correlations of ZM-IOFo, ZM-ANS, and IOFo-IOFi with the right OV, left OV, and average OV.

The coefficients of the correlations between the study variables and OV in Groups 1, 2, and 3 are presented in Tables 4–6, respectively. Significant negative correlations were observed between sex and OV, specifically in relation to the right OV, left OV, and average OV, in the 3 groups. Furthermore, significant positive correlations were noted between body height and the right OV, left OV, and average OV in the 3 groups. Significant negative correlations were observed between skeletal patterns and OV in Group 3, but such correlations were not observed in Group 1. VMA values demonstrated a significant negative correlation with OV in only Group 3. Moreover, most maxillary dimensions on both sides exhibited significant positive correlations with the right OV, left OV, and average OV. Finally, VMA values exhibited no significant correlations with maxillary dimensions (ZM-IOFo, ZM-ANS, and IOFo-IOFi) in Groups 1 and 2.

Table 3 Pearson's correlation coefficient (*r*) between orbital volume (OV) and variables in the total participants.

Variables	OV (right)	OV (left)	OV (total)	DOV	VMA value
Group	−0.023	−0.103	−0.064	0.241*	0.269*
Sex	−0.753*	−0.704*	−0.739*	−0.152	0.272*
Age	0.028	0.021	0.025	0.022	0.043
Height	0.714*	0.701*	0.718*	0.047	−0.203*
SNA	0.128	0.114	0.123	0.042	0.111
SNB	0.094	0.127	0.112	−0.098	0.045
ANB	0.011	−0.039	−0.015	0.149	0.041
Skeletal pattern	−0.018	0.026	0.004	−0.132	0.081
VMA value	−0.211*	−0.296*	−0.257*	0.252*	1
Right side					
ZM-IOFo	0.490*	0.426*	0.465*	0.195	−0.214*
ZM-ANS	0.551*	0.520*	0.543*	0.099	−0.201
IOFi-IOFo	0.503*	0.507*	0.512*	−0.009	−0.072
Jr-SFP	0.565*	0.539*	0.560*	0.083	0.020
Left side					
ZM-IOFo	0.361*	0.380*	0.376*	−0.052	−0.227*
ZM-ANS	0.447*	0.410*	0.435*	0.115	−0.143
IOFi-IOFo	0.528*	0.576*	0.559*	−0.139	−0.151
Jr-SFP	0.607*	0.616*	0.620*	−0.022	−0.377*

OV: orbital volume, DOV: difference between right and left OV, VMA: vertical maxillary asymmetry, ZM: zygomatic maxillary suture, IOFo: inferior orbital foramen, ANS: anterior nasal spine, IOFi: inferior orbital fissure, Jr: jugular, SFP: superior facial plane.
r: 0.00–0.19 "very weak" 0.20–0.39 "weak" 0.40–0.59 "moderate" 0.60–0.79 "strong" 0.80–1.0 "very strong".
*: Statistical significance, $P < 0.05$.

Table 4 Pearson's correlation coefficient (*r*) between orbital volume (OV) and variables in the Group 1 participants.

Variables	OV (right)	OV (left)	OV (total)	DOV	VMA value
Sex	−0.778*	−0.690*	−0.745*	−0.334	0.030
Age	0.182	0.181	0.184	0.021	−0.057
Height	0.704*	0.608*	0.666*	0.350*	−0.152
SNA	0.153	0.150	0.154	0.026	0.073
SNB	−0.049	0.093	0.021	−0.417*	−0.036
ANB	0.212	0.049	0.134	0.495*	0.056
Skeletal pattern	−0.001	0.069	0.034	−0.205	−0.220
VMA vaule	−0.041	−0.108	−0.075	0.191	1
Right side					
ZM-IOFo	0.524*	0.392*	0.466*	0.437*	−0.115
ZM-ANS	0.658*	0.618*	0.648*	0.182	−0.128
IOFi-IOFo	0.333	0.331	0.337	0.038	0.077
Jr-SFP	0.637*	0.0584*	0.620*	0.216	0.087
Left side					
ZM-IOFo	0.414*	0.384*	0.405*	0.129	−0.125
ZM-ANS	0.507*	0.485*	0.503*	0.113	−0.052
IOFi-IOFo	0.356*	0.415*	0.391*	−0.133	−0.019
Jr-SFP	0.644*	0.599*	0.631*	0.194	−0.033

OV: orbital volume, DOV: difference between right and left OV, VMA: vertical maxillary asymmetry, ZM: zygomatic maxillary suture, IOFo: inferior orbital foramen, ANS: anterior nasal spine, IOFi: inferior orbital fissure, Jr: jugular, SFP: superior facial plane.
r: 0.00–0.19 "very weak" 0.20–0.39 "weak" 0.40–0.59 "moderate" 0.60–0.79 "strong" 0.80–1.0 "very strong".
*: Statistical significance, $P < 0.05$.

Discussion

Individuals with vertical maxillary asymmetry (VMA) often present with noticeable maxillary dental canting, typically observed in the region of the bilateral maxillary second premolars. Lombardo et al.[17] reported that the inter–first premolar distance in the maxilla was 48 mm, while the mandibular inter–second premolar distance was 49 mm. Similarly, Park et al.[18] analyzed the dental arch dimensions and shapes in Korean young adults and found that the mean maxillary inter–second premolar distance was 50.9 mm across three arch types (V-shaped, ovoid, and U-

Table 5 Pearson's correlation coefficient (*r*) between orbital volume (OV) and variables in the Group 2 participants.

Variables	OV(right)	OV (left)	OV (total)	DOV	VMA value
Sex	−0.810*	−0.787*	−0.812*	0.043	0.192
Age	0.072	0.079	0.077	−0.028	0.067
Height	0.809*	0.829*	0.834*	−0.161	−0.141
SNA	0.135	0.133	0.136	−0.011	0.243
SNB	0.408*	0.419*	0.421*	−0.086	−0.111
ANB	−0.322	−0.337	−0.335	0.085	0.364*
Skeletal pattern	0.331	0.358*	0.351	−0.120	−0.026
VMA value	−0.164	−0.205	−0.188	0.137	1
Right side					
ZM-IOFo	0.422*	0.395*	0.415*	0.019	−0.036
ZM-ANS	0.483*	0.452*	0.475*	0.021	0.097
IOFi-IOFo	0.487*	0.470*	0.487*	−0.016	0.226
Jr-SFP	0.386*	0.442*	0.422*	−0.207	−0.126
Left side					
ZM-IOFo	0.120	0.217	0.172	−0.283	−0.003
ZM-ANS	0.392*	0.334	0.369*	0.111	0.103
IOFi-IOFo	0.546*	0.598*	0.582*	−0.216	0.060
Jr-SFP	0.403*	0.467*	0.443*	−0.232	−0.433*

OV: orbital volume, DOV: difference between right and left OV.
VMA: vertical maxillary asymmetry, ZM: zygomatic maxillary suture, IOFo: inferior orbital foramen, ANS: anterior nasal spine, IOFi: inferior orbital fissure, Jr: jugular, SFP: superior facial plane.
r: 0.00—0.19 "very weak" 0.20—0.39 "weak" 0.40—0.59 "moderate" 0.60—0.79 "strong" 0.80—1.0 "very strong".
*: Statistical significance, $P < 0.05$.

Table 6 Pearson's correlation coefficient (*r*) between orbital volume (OV) and variables in the Group 3 participants.

Variables	OV(right)	OV (left)	OV (total)	DOV	VMA value
Sex	−0.680*	−0.665*	−0.678*	−0.135	0.492*
Age	−0.093	−0.089	−0.091	−0.026	0.090
Height	0.687*	0.695*	0.697*	0.047	−0.268
SNA	0.097	0.026	0.063	0.286	0.166
SNB	−0.009	−0.107	−0.058	0.376*	0.122
ANB	0.072	0.135	0.104	−0.237	−0.030
Skeletal pattern	−0.396*	−0.409*	−0.405*	0.004	0.200
VMA value	−0.380*	−0.496*	−0.441*	0.406*	1
Right side					
ZM-IOFo	0.522*	0.522*	0.526*	0.059	−0.511*
ZM-ANS	0.510*	0.463*	0.491*	0.237	−0.424*
IOFi-IOFo	0.702*	0.720*	0.717*	0.007	−0.205
Jr-SFP	0.645*	0.592*	0.624*	0.280	0.069
Left side					
ZM-IOFo	0.558*	0.551*	0.559*	0.090	−0.515*
ZM-ANS	0.424*	0.354	0.392*	0.320	−0.267
IOFi-IOFo	0.710*	0.725*	0.723*	0.020	−0.245
Jr-SFP	0.773*	0.790*	0.788*	0.023	−0.486*

OV: orbital volume, DOV: difference between right and left OV.
r: 0.00—0.19 "very weak" 0.20—0.39 "weak" 0.40—0.59 "moderate" 0.60—0.79 "strong" 0.80—1.0 "very strong".
*: Statistical significance, $P < 0.05$.

shaped). Based on these findings, the maxillary inter—second premolar distance can be inferred to be approximately 50 mm. Clinically, each 1° increase in occlusal plane canting corresponds to about a 1 mm vertical dental discrepancy. Alhuwaish and Almoammar[19] proposed an occlusal cant index based on the perceptibility of occlusal canting among orthodontists and laypersons. They found that the detection threshold was approximately 2° for orthodontists and 4° for laypersons, with a significant perceptual difference between 2° and 3° of tilt. Accordingly, in the present study, a VMA value greater than 2 mm was considered indicative of significant asymmetry, consistent with clinical observations and professional orthodontic assessment.

Chang et al.[20] reported a significant relationship between orbital growth and craniofacial development. They noted a distinct pattern of accelerated growth that subsequently tapered off with age; their results indicated that by the age of 6, the depth of the orbit was approximately 90 % of its adult size, and by the age of 13, it reached approximately 98 % of its adult dimensions. Similarly, Farkas et al.[21] conducted an age-related study on growth variations in intercanthal width and biocular width among 1594 healthy North American Caucasians aged 1–18 years. Their results revealed that intercanthal width reached full maturity by the age of 8 years in female individuals and 11 years in male individuals; moreover, biocular width reached full maturity by the age of 13 years in female individuals and 15 years in male individuals. Chau et al.[22] applied MRI to investigate orbital development in 81 individuals aged 1–42 years in China. They observed that OV grew most rapidly during early childhood and adolescence, reaching its mature size by approximately 16 years of age. In the present study, participates were aged between 20 and 30 years; hence, their eyeballs and orbital bones had fully matured, and the measurements were not influenced by developmental changes or the aging process.

Wen et al.[23] reviewed various angular and linear measurements of the face and identified distinct ethnic and racial differences in facial features among African, Asian, and Caucasian populations. In regard to frontal face width, the findings reveal that Asian individuals possess the widest faces, followed by African individuals, while Caucasian individuals have the narrowest. Additionally, across all ethnic groups, men display a greater frontal face width compared to women. Furthermore, Chung et al.[24] investigated the effect of race and ethnicity on 6 cephalometric measurements in a cohort of 9912 school-aged children in Hawaii. These measurements comprised facial height, head width, head length, and the head index, in addition to the dimensions of the maxilla and mandible. They observed that individuals of Chinese, Japanese, Korean, and Filipino descent generally exhibited a longer transverse dimension and shorter anterior-posterior dimension compared with those of Caucasian descent. Accordingly, orbital size and OV differ considerably between sexes and among different ethnic groups.

All participates in our study were aged >20 years. Hence, their orbits were fully developed; this thus explains the lack of notable differences in age or OV among the 3 groups. Friedrich et al.[25] used CBCT to evaluate OV in a German population. Their results revealed a mean OV of approximately 28 mm^3 in men, which was considerably larger than the average OV of approximately 24 mm^3 in women. Additionally, their study demonstrated no significant differences in OV between the left and right orbits for either sex. Similarly, Khani et al.[26] examined an Iranian population and reported that the average OV for men was approximately 25 mm^3, which was significantly larger than that observed for women (approximately 23 mm^3). Furthermore, Furuta[27] included a population of Japanese adults and reported similar findings, with men having an average OV of approximately 23.6 mm^3, which was significantly larger than that observed in women (approximately 20.9 mm^3). Shyu et al.[16] also conducted a study in Taiwan and reported that men exhibited an average OV of approximately 24 mm^3, which was significantly larger than that observed among women (approximately 21 mm^3). These findings indicate that the size of the orbit is influenced by ethnicity. Specifically, individuals from Western backgrounds tend to have larger orbits compared with those from Eastern backgrounds.

Additionally, orbits are generally larger in men than in women. The findings of the present study are consistent with those of the aforementioned studies, demonstrating that men exhibited larger right, left, and overall OVs than did women. Additionally, in each of the VMA groups, men exhibited a significant increase in OV compared with women, indicating a strong correlation between OV and sex. The study also observed a significant relationship between sex and VMA in the study sample, particularly in Group 3. This suggests a sex-related trend in facial asymmetry. This may be attributed to the observation that female participates often place greater emphasis on the symmetry of their appearance, leading to a larger sample of women seeking medical treatment. Moreover, our findings revealed a strong to very strong correlation between OV and height in the 3 groups and in the overall participate. Specifically, increased height was associated with larger OVs. This finding may explain why Caucasians, who tend to be taller than Asians, also have larger OVs. However, DOV did not demonstrate a consistent relationship with height in the 3 groups.

In this study, we observed notable differences in VMA values among the 3 groups. Group 3 exhibited the highest VMA value, followed by Group 2 and then Group 1. The VMA value in Group 3 was significantly greater than that in Group 1. Furthermore, our results indicate no significant differences in the mean right OV, left OV, or overall OV or DOV among the 3 groups, but they reveal the following trend: Group 3 exhibited the highest values, followed by Group 2 and Group 1. This pattern suggests that as the VMA value increases, the DOV value also tends to increase. Specifically, in Group 3 and the total participates, a moderate positive correlation was observed between the VMA and DOV, indicating that higher VMA values correspond to greater increases in DOV. Furthermore, the OV did not exhibit a significant correlation with the 3 skeletal patterns in the overall participates. However, VMA value was negatively correlated with the mean right OV, left OV, and overall OV in the group 3. We also examined the associations of SNA, SNB, and ANB with OV. The results reveal that SNA was not significantly correlated with OV. By contrast, SNB exhibited a significant correlation with OV in Groups 1, 2, and 3. Notably, in participates with a Class III relationship, as SNB increased, a corresponding decrease in OV was observed.

OV was also significantly correlated with the distances between ZM-IOFo, IOFo-IOFi, and ZM-ANS in each group and in the study sample. This finding indicates a relationship between the size of the orbit and the growth of the maxilla. Specifically, a wider, longer, and deeper maxilla is associated with an increase in OV. The VMA values for all participates exhibited a weak correlation with DOV. Nevertheless, in clinical practice, maxillary canting is typically defined as a difference of >2 mm in VMA measurements between the left and right sides. In our study, Group 3, which exhibited a relatively high degree of

maxillary canting, had a moderate correlation with DOV. By contrast, Groups 1 and 2, which exhibited relatively low levels of maxillary canting, did not have a significant correlation with DOV.

This study has several limitations: (1) The sample size remains relatively small and may not fully represent the general population; (2) Future analyses should compare male and female subjects separately to explore potential gender-related differences; and (3) The grouping criteria could be refined by adding a VMA $\geq$4 mm category to represent severe asymmetry, which corresponds to a level of maxillary cant that is visually perceptible to the naked eye.

In conclusion, a significant association was identified between sex and OV, with females exhibiting smaller OVs than males. OV demonstrated a significant positive correlation with height and a negative correlation with VMA, whereas DOV exhibited a positive correlation with VMA, particularly within Group 3. The robust positive relationship between VMA and DOV indicates that an increase in VMA is concomitant with enhanced maxillary development and a corresponding elevation in OV on the same side.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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