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Sex-specific correlations between orbital volume and anthropometric characteristics in Taiwanese adults

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KEYWORDS
Orbital volume;
Patient's characteristics;
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Height

Abstract *Background/purpose:* There is no study available addressing the relationship between orbital volume (OV) and skeletal patterns. The purpose of this study was to investigate the correlations between the OV and patient's characteristics (sex, age, height, and skeletal patterns) of Taiwanese adults.
Materials and methods: Cone-beam computed tomography images of 94 individuals (men: 47; women: 47) were analyzed to measure their OV and maxillary dimensions. The Student t test was used to compare the OVs of men and women. The correlations between the OV and skeletal patterns (Classes I, II, and III) were investigated through one-way analysis of variance followed by post hoc Bonferroni correction.
Results: The mean OV was significantly larger in the men than in the women (25.67 ± 1.89 cm^3 vs 22.21 ± 1.23 cm^3, respectively). In men with a Class I, II, or III skeletal pattern, the mean OV was 25.50 ± 1.70 cm^3, 26.42 ± 2.17 cm^3, and 25.14 ± 1.62 cm^3, respectively. The mean OV was significantly larger in individuals with a skeletal Class II relationship than in those with a skeletal Class I and Class III relationship. The mean OVs (right OV, left OV and total OV) and maxillary dimensions were significant correlated with height. No significant differences were noted in skeletal patterns in the sex-specific group.
Conclusion: Men tend to have a larger OV than do women. The OV and maxillary dimensions were significantly correlated with height. Furthermore, the OV does not vary significantly between sex-specific groups with different skeletal patterns.

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Introduction

The human orbit is a hyperbolic paraboloid in shape and resembles a saddle-shaped surface. When the orbit is filled with a material, a true surface is created.[1] Ex vivo studies investigating tools for OV measurement have filled orbits with lead pellets, sand, or hard seeds and then calculated the volume.[1] The first case of OV measurement was reported in 1873, when Gayat measured the OV by filling 11 adult orbits with lead pellets.[1] Subsequently, Alexander et al.[2] measured the OV by filling orbits with sand and hard seeds, respectively. Sarnat et al.[3] were the first to measure the OV by using an imprint method (cast molding): they molded elastic rubber polymers to capture the shape of rabbit orbits and then measured the volume of the material. With the advancement of medical-imaging techniques, magnetic resonance imaging,[4] computed tomography (CT)[5–7] and cone-beam computed tomography (CBCT)[8,9] have emerged as popular techniques for the in vivo measurement of human OV.

The human orbit comprises 7 bones, one of which is the maxilla. The orbital surface of the maxilla constitutes a major portion of the orbit floor. The orbital volume (OV) could be influenced by facial trauma and disease. Accurately measuring the orbital size remains a challenging task. To ensure optimal outcomes after orbital surgery, surgeons require pertinent information on orbital growth and development. Moreover, studies[10,11] exploring rapid maxillary expansion have demonstrated that such expansion extends well beyond the median palatine suture to the orbital, frontal, and parietal bones. The variations of facial skeletal patterns include maxillary or mandibular deformity (deficiency or overgrowth). However, the correlation between the patient's characteristics (sex, age, height, and skeletal patterns) and the OV remains unclear. Therefore, the present study was conducted to investigate the correlations between the OV and anthropometric characteristics in Taiwanese adults.

Materials and methods

Cone-beam computed tomography (CBCT) images were obtained using a CBCT device (NewTom VGi evo, Imola, Italy) at the Department of Dentistry, Kaohsiung Medical University Hospital. The radiation parameters were 110 kV and 4.59 mA, and the exposure duration was 3.5 s. This study included individuals aged $\geq$20 years who had a normal orbital structure. Individuals with a history of maxillofacial trauma; those with a congenital craniofacial deformity or syndrome; and those with a surgical history of eye, orbital, or orthognathic surgery were excluded. The images were imported as digital imaging and communications in medicine (DICOM) files into 3D Slicer (version 4.11) for 3-dimensional volume rendering. The segmentation step involved selecting the grayscale intensity level of voxels across the entire data set to measure the volume of the reconstructed CT data.

For measurements, a method introduced by Shyu et al.[12] was employed. The orbit's anterior boundary was defined as the straight line connecting the inner and outer orbital rims, whereas its posterior boundary was defined as the shortest line connecting bony structures. The following landmarks were used: Sella (S), Ba (basion), N (nasion), A point (A), and B point (B), Ga (glabella), Or (orbitale), and Po (porion). The midpoint of the line connecting Or (R [right side]) and Or (L [left side]) was denoted Or (Mid [midpoint]) and that of the line connecting Po(R) and Po(L) was denoted Po(Mid). The Frankfort horizontal line was obtained by connecting Or (Mid) and Po (Mid). The midsagittal plane was obtained by connecting Ga, N, and Ba. Then, the Frankfort horizontal line and midsagittal plane were used to establish a coordinate system. Lateral cephalometric images were analyzed using ImageJ (version 1.48v). The SNA angle, SNB angle, and ANB angle were measured for the classification of skeletal patterns. Following the guidelines of Riedel,[13] this study divided skeletal relationships into the following 3 classes: Class I, ANB angle $= 0^\circ$ to 4°; Class II, ANB angle $>4^\circ$; and Class III, ANB angle $<0^\circ$. For measurements, the following reference points and planes were employed: zygomaticomaxillary suture (ZM), inferior orbital foramen (IOFo), anterior nasal spine (ANS), inferior orbital fissure (IOFi). The following maxillary dimensions were measured: ZM-IOFo, ZM-ANS, and IOFi-IOFo (Fig. 1). The orbital boundary surface was shown in Fig. 2. The OVs were reconstructed and measured by 3D Slicer (version 4.11). The target area is initially circled in the axial view of the CBCT scan and verified in the sagittal view. Then, the concept of integration is applied to overlay the circled areas on each section, ultimately forming the target volume. Utilizing computer-assisted machine learning and Gaussian smoothing, the final OV is determined.

The interclass and intraclass reliability values ranged from 0.90 to 0.97 and from 0.87 to 0.98, respectively. Statistical analyses were performed using SPSS (version 23.0; IBM, Armonk, NY, USA). A P value of <0.05 was regarded as statistically significant. The Student t test was used to compare the study variables between the sexes. The differences between the OV and skeletal patterns were investigated through one-way analysis of variance followed by post hoc Bonferroni correction. Pearson's Correlation coefficient (r) test was used to investigate the relationship between variables and VO and maxillary dimensions. The absolute value of r is interpretable as: 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". The null hypothesis is that there is no significant correlation between patient's characteristics and OV.

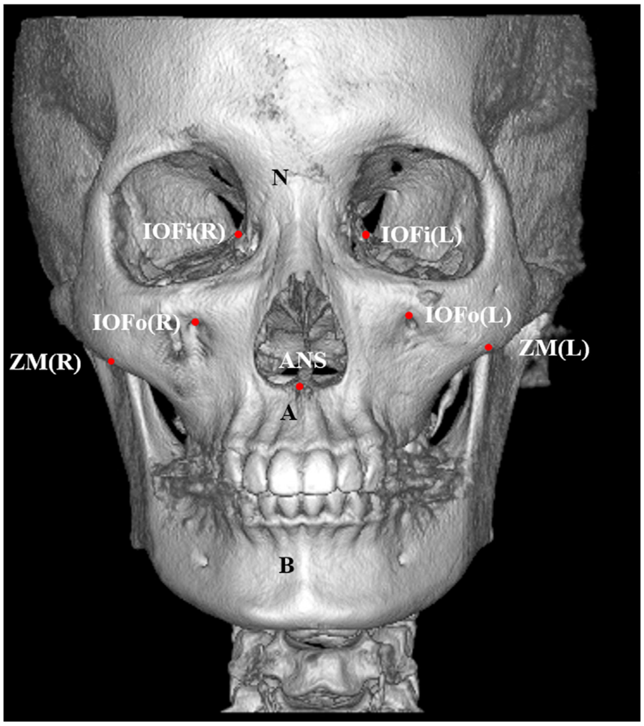

Figure 1 Landmarks: N (nasion), A point (A), B point (B), zygomaticomaxillary suture (ZM), inferior orbital foramen (IOFo), anterior nasal spine (ANS), inferior orbital fissure (IOFi), R: right side, L: left side.

Results

This study included 94 participants (men: 47; women: 47; Table 1). The mean ages of the male and female participants were 26.3 ± 6.46 (range, 20 to 47) years and 27.19 ± 7.16 (range, 20 to 59) years, respectively. The mean height of the men was 173.10 ± 5.79 cm and that of the women was 159.88 ± 5.60 cm. The skeletal pattern of the participants was classes I, II, and III in 28 (men: 12; women: 16), 32 (men: 16; women: 16), and 34 (men: 19; women: 15) participants, respectively.

The mean length of ZM-IOFo on the right side was significantly longer in the men than in the women (24.85 ± 2.88 mm vs 22.97 ± 2.54 mm, respectively; Table 1). The mean length of ZM-ANS on the right side was significantly longer in the men than in the women (51.90 ± 2.57 mm vs 48.86 ± 2.16 mm, respectively). The mean length of IOFo-IOFi on the right side was significantly longer in the men than in the women (44.71 ± 3.13 mm vs 42.91 ± 2.38 mm, respectively).

The mean OV was 25.67 ± 1.89 cm^3 for the men and 22.21 ± 1.23 cm^3 for the women (Table 2). The OVs (mean OV, left OV, right OV, Class I, Class II, and Class III) were significantly larger in the men than women. In men with a Class I, II, or III skeletal pattern, the mean OV was 25.50 ± 1.70, 26.42 ± 2.17, and 25.14 ± 1.62 cm^3, respectively. The OV did not vary significantly between the men with differing skeletal patterns ($P = 0.127$). In the women with a Class I, II, or III skeletal pattern, the mean OV was 22.38 ± 1.29 cm^3, 22.18 ± 1.40 cm^3, and 22.05 ± 1.01 cm^3, respectively. The OV did not vary significantly between the women with differing skeletal patterns ($P = 0.759$). In total patients, the trend in the OV was as follows: skeletal Class II > Class III > Class I. In the men, the trend in the OV was as follows: skeletal Class II > Class I > Class III. In the women, this trend was as follows: skeletal Class I > Class II > Class III.

The mean OVs (right OV, left OV and total OV) were strong correlated with height (Table 3). Therefore, the null hypothesis is rejected. Most of maxillary dimensions (ZM-IOFo, ZM-ANS, and IOFi-IOFo) were moderate correlated with mean OVs (right OV, left OV and total OV). No significant correlation was found between the OV and SNA, SNB, ANB, or any skeletal pattern (class I, II, or III). The correlations between the patient's characteristics and maxillary dimensions are presented in Table 4. In the right and left sides of maxilla, the ZM-IOFo and ZM-ANS were significantly correlated with height from weak to moderate correlation. Both sides of IOFi-IOFo were moderate correlated with height. Skeletal patterns revealed no significant correlation with maxillary dimensions.

Discussion

Osaki et al.[1] compared 3 common methods of OV measurement: indirect measurement by analyzing CT images; direct measurement by removing the orbital content, molding a silicone cast, and measuring the cast's volume through water displacement; and direct measurement by filling the orbit with 1-mm^3 glass beads and using a graduated cylinder to measure the material volume. They found that OVs measured using the direct methods were higher than those measured using the indirect method. The between-method differences in measurements can be attributed to variation in the definition of the anterior orbital limit and curve.

Numerous studies[8,14,15] have demonstrated congenital differences in the OV between races. Friedrich et al.[8] analyzed CBCT images of 50 German men and 50 German women; they found that the OV increases slightly with age, from 24.99 mL between the ages of 20 and 29 years. Amin et al.[14] compared the OVs of 30 African American with those of 30 Caucasian adults. The mean OV of the African American individuals was smaller than that of the Caucasian individuals (22.38 cm^3 vs 23.23 cm^3). Furuta[16] studied the OV and growth in 109 Japanese individuals (men: 74; women: 35) by using CT images. Furuta[16] found that the OV started increasing rapidly at the age of 14.9 years in boys and 10.9 years in girls. By adolescence, the OV reached 95 % of its size in adults. Between the ages of 18 and 40 years, the mean OV was 23.64 cm^3 in men and 20.89 cm^3 in women. Our study presented the mean OV was 25.67 cm^3 in men and 22.21 cm^3 in women. The differences in measurements can be attributed to variation in the definition of the anterior orbital limit and curve. Moreover, genetic and environmental factors can influence height. For most people, height stops increasing after the age of 20 years. In all races, men are typically taller than women. In general, White and Black individuals are taller than Asian and Hispanic individuals. In the present study, men were significantly taller than women. The OV (mean OV, left OV, and

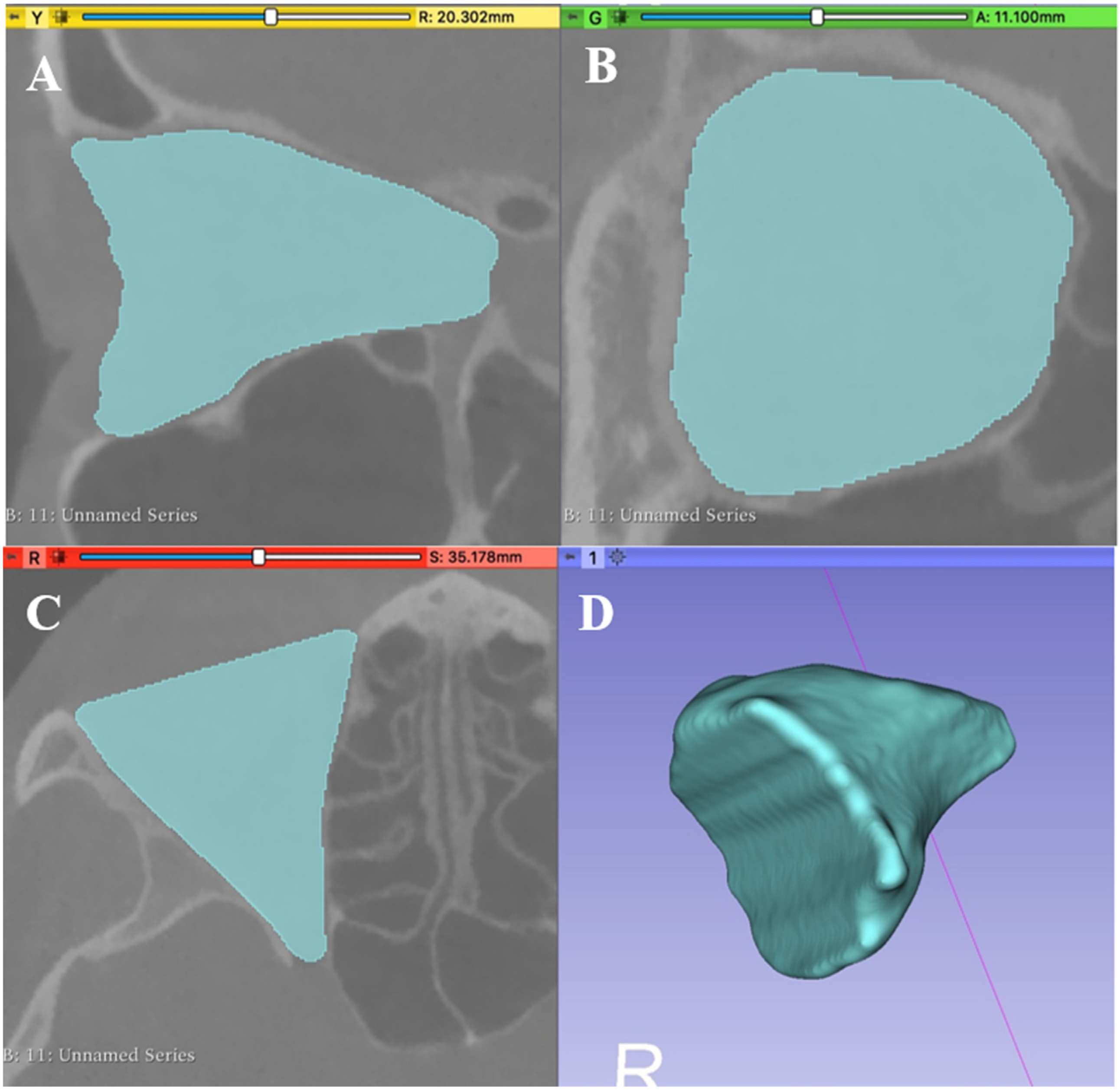

Figure 2 Orbital boundary and orbital volume was reconstructed and measured by 3D Slicer. A: Sagittal view B: Coronal view C: Axial view D: Three dimensional image.

right OV) was significantly larger in men than in women. Shyu et al.[12] measured the OV of 20 Taiwanese adults (men: 10; women: 10) and found that the mean OVs of the right and left eyes were 24.7 cm^3 and 24.3 cm^3, respectively. Our result was similar to report of Shyu et al.[12] The differences in left and right OVs were nonsignificant in men and women.

Thalassemia is a genetic disorder characterized by the abnormal production of hemoglobin. This condition results from the impairment of hematopoiesis and the dysfunction of red blood cells and results in malformation of the skull and long bones. In patients with thalassemia, hematopoiesis occurs in the maxilla, pushing the orbits outward and thereby resulting in hypertelorism. This fact confirms that maxillary changes affect the orbital structure. In particular, patients with thalassemia major may develop Class II malocclusion after maxillary protrusion and mandibular atrophy.[16,17] The maxilla is often well-developed or overdeveloped in patients with class II relationships. Because the maxilla constitutes a large portion of the orbit, a well-developed or overdeveloped maxillary bone results in a well-developed orbital region and relatively large OV in individuals with Class II relationships. In the present study, regardless of skeletal pattern, the mean OV was significantly larger in men than in women. Moreover, regardless of sex, the mean OVs of the right and left eyes were larger in individuals with Class II relationships than in those with Class III relationships. However, the corresponding interclass differences did not vary significantly between the sexes. The trend in the OV for men was skeletal Class

Table 1 Summary of patient characteristics and skeletal patterns.

	Male (n = 47)		Female (n = 47)		Male *vs* Female
	Mean	SD	Mean	SD	(*P* value)
Age (year)	26.32	6.46	27.19	7.16	0.537
Height (cm)	173.10	5.79	159.88	5.60	<0.001*
SNA (degree)	82.80	4.53	82.16	4.34	0.483
SNB (degree)	81.37	5.43	79.92	6.14	0.229
ANB (degree)	1.44	5.32	2.14	5.24	0.523
Right side					
ZM-IOFo (mm)	24.85	2.88	22.97	2.54	<0.001*
ZM-ANS (mm)	51.90	2.57	48.86	2.16	<0.001*
IOFo-IOFi (mm)	44.71	3.13	42.91	2.38	0.002*
Left side					
ZM-IOFo (mm)	24.00	2.79	23.08	2.64	0.105
ZM-ANS (mm)	51.72	2.83	49.2	2.45	<0.001*
IOFo-IOFi (mm)	45.24	3.21	42.83	2.82	<0.001*

n: number of participant.
*: Statistical significance, $P < 0.05$.
ZM-IOFo: the distance from zygomaticomaxillary suture to inferior orbital foramen.
ZM-ANS: the distance from zygomaticomaxillary suture to anterior nasal spine.
IOFo-IOFi: the distance from inferior orbital foramen to inferior orbital fissure.

Table 2 Orbital volume (OV) in the comparisons of gender differences and skeletal pattern.

	Male		Female		Male *vs* Female
	Mean	SD	Mean	SD	(*P* value)
Total OV (mL)	25.67	1.89	22.21	1.23	<0.001*
Right OV (mL)	25.83	1.86	22.25	1.24	<0.001*
Left OV (mL)	25.51	1.98	22.17	1.36	<0.001*
Classification					
Class I OV (mL)	25.50	1.70	22.38	1.29	<0.001*
Class II OV (mL)	26.42	2.17	22.18	1.40	<0.001*
Class III OV (mL)	25.14	1.62	22.05	1.01	<0.001*
Interclass OV comparison					
P value	0.127		0.759		

*: Statistical significance, $P < 0.05$.

II > Class I > Class III and that for women was skeletal Class I > Class II > Class III. Most individuals with a Class II relationship had a larger OV than did those with a class I relationship, except for the left OV in women. The present study revealed a correlation between maxillary development and the OV.

The growth and development of facial features are influenced by sex hormones. Sex hormones are well-established as important factors in bone metabolism. Fujita et al.[18] conducted a study to examine how disturbances in sex hormone levels affect craniofacial development in newborn mice. Their findings revealed a significant reduction in growth within the nasomaxillary bone and mandible. These results indicate that alterations in sex hormone levels may inhibit craniofacial growth, not only during puberty but also immediately after birth. However, the role of sex hormones in the development of craniofacial structures in humans remains unclear. Chau et al.[19] studied the magnetic resonance imaging data of 81 Chinese individuals (age: 1 to 42 years) and found that the OV increased most rapidly during early life and puberty and reached maturity (21.00 cm^3) at the age of approximately 16 years. After the age of 18 years, the mean OV was significantly larger (by 2.53 cm^3) in men than in women. In our study, the maxillary dimensions (ZM-IOFi, ZM-ANS, and IOFo-IOFi), except for the left ZM-IOFi, were significantly larger in men than in women. This finding can be explained by the effects of sex hormones on facial growth. Our findings revealed that the OV is correlated with the size of the maxilla. In summary, the maxillary dimensions and OV were found to be significantly larger in men than in women. Consequently, the growth of bones and levels of hormones during the period of sexual maturity can influence facial features, including the maxilla, zygomatic bone, orbital region, nasal bone, and mandible.

Given the correlations between the OVs and patients' characteristics, a strong correlation between the OV and height was discovered. It means that taller people may be more likely to have a larger OV than shorter people. Similarly, we also found that height was significant correlated

Table 3 Pearson's Correlation coefficient (r) between orbital volume (OV) and variables.

Variables	Right OV	Left OV	Total OV
Age	0.028	0.021	0.025
Height	0.714*	0.701*	0.718*
SNA	0.128	0.114	0.123
SNB	0.094	0.127	0.112
ANB	0.011	−0.039	−0.015
Skeletal pattern	−0.018	0.026	0.004
Right side			
ZM-IOFo	0.490*	0.426*	0.465*
ZM-ANS	0.551*	0.520*	0.543*
IOFi-IOFo	0.503*	0.507*	0.512*
Left side			
ZM-IOFo	0.361*	0.380*	0.376*
ZM-ANS	0.447*	0.410*	0.435*
IOFi-IOFo	0.528*	0.576*	0.559*

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, $P < 0.05$.
ZM-IOFo: the distance from zygomaticomaxillary suture to inferior orbital foramen.
ZM-ANS: the distance from zygomaticomaxillary suture to anterior nasal spine.
IOFi-IOFo: the distance from inferior orbital fissure to inferior orbital foramen.

with maxillary dimensions. The taller people have a large maxilla than shorter people. However, the SNA and skeletal patterns didn't present significant correlation with OV and maxillary dimensions. However, it is essential to take into account the possible differences between various imaging techniques and equipment, as these discrepancies could significantly affect the precision of orbital volume measurements. Schmutz et al.[20] found that MRI models generally underestimated orbital volume in comparison to CT models, and this discrepancy was statistically significant. Chepurnyi et al.[21] investigated orbital volume using three different segmentation techniques: manual, semi-automated, and automated. The results of their study revealed significant differences among the various methods employed. Automated segmentation produced the highest measurements, followed by semi-automated techniques, and finally manual segmentation. This discrepancy can be attributed to differences in the definitions of anterior orbital closure utilized in each method.

The primary limitation of this study is the small sample size in each of the three skeletal pattern groups. Furthermore, there are fewer than 20 individuals of both genders in each group. Consequently, it can be challenging to accurately reflect the characteristics of the entire population. In further research, we aim to explore the orbital volume in relation to the technologies in the automated segmentation of CT and the computer-aided design and computer-aided manufacturing (CAD-CAM). Additionally, our goal is to obtain optimal results in image analysis, differential diagnosis, virtual surgical planning (VSP), reconstruction design, real-time surgical interventions, and overall treatment outcomes.

In conclusion, the OV was significantly larger in men than in women. In both men and women, the OV was significantly correlated with height. Regardless of sex, individuals with a class II relationship had a larger OV than did those with a Class III relationship. Furthermore, the OV was significantly correlated with most maxillary parameters in men.

Table 4 Pearson's Correlation coefficient (r) between orbital maxillary dimensions and variable.

Variables	Right			Left		
	ZM-IOFo	ZM-ANS	IOFi-IOFo	ZM-IOFo	ZM-ANS	IOFi-IOFo
Age	−0.084	−0.092	0.005	−0.066	−0.149	−0.015
Height	0.363*	0.413*	0.433*	0.262*	0.358*	0.457*
SNA	−0.034	0.074	0.009	0.021	0.121	0.077
SNB	−0.102	−0.118	−0.041	−0.157	−0.094	0.070
ANB	0.075	0.195	0.059	0.173	0.204*	0.000
Skeletal pattern	−0.008	0.000	−0.086	−0.077	−0.015	0.020

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, $P < 0.05$.
ZM-IOFo: the distance from zygomaticomaxillary suture to inferior orbital foramen.
ZM-ANS: the distance from zygomaticomaxillary suture to anterior nasal spine.
IOFi-IOFo: the distance from inferior orbital fissure to inferior orbital foramen.

Declaration of competing interest

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

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